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Public Interest Energy Research Program

HPCBS # E2P2.1T3d

HPCBS

High Performance Commercial Building Systems

Benchmarking Performance Assessment for Small Commercial Buildings
Final Report

Element 2 - Life Cycle Tools
Project 2.1 - Benchmarking and Performance Metrics
Task 2.2.3 - Benchmarking and Performance Assessment for Small Commercial Buildings

L. K. Norford, R. Palomera-Arias and J.S. Ramsey
Building Technology Program
Department of Architecture
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139
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Introduction

The intent of Task 2.1.3 is to determine how a small sample of people involved in operating buildings can make use of benchmarked energy-consumption data. To elaborate, until very recently benchmarking data have been the province of energy analysts and not those who operate businesses and pay energy bills. Examples of such data include the surveys of residential and commercial buildings performed by the U.S. Department of Energy's Energy Information Agency (EIA). As part of Element 2, other researchers (at LBNL) have developed a Web-based benchmarking tool that will permit a user to compare an energy-use intensity (EUI, annual energy consumption normalized by floor area) to the consumption of similar buildings. This tool, Cal-Arch, includes CEUS (Commercial End-Use Survey) data sets for California buildings and is intended to appeal to:

- Energy service companies and performance contractors
- Full-service control companies
- Organizations interested in including energy performance in building appraisals
- Designers
- Energy managers and building owners
- Software developers and energy consultants

For Task 2.1.3, the focus is on building owners. Are they interested in benchmarks? How will they use them? Are they interested in sharing energy information with others in similar positions, as a means of comparing notes and determining further steps to control energy costs?

A second but still crucial element of Task 2.1.3 is the application of advanced technology to obtain energy information at selected sites. To compare energy consumption at a particular building to an EUI-based benchmark requires nothing more than a year of energy bills. The user of a benchmarking tool then must assess why the EUI for the site in question differs from that of supposedly comparable buildings. Longer hours of operation? Special equipment? More widgets produced? Not yet able to afford an overdue lighting retrofit? End-use information can be used to pinpoint areas of relatively high energy consumption. If a benchmark includes end-use information, then end-use information for the site in question is essential.

In small non-residential buildings (retail, restaurants, schools), obtaining end-use information or even time-of-use whole-building information requires metering not typically installed. The cost of such metering is widely perceived by energy analysts to be a barrier. It is not clear that the additional information would in fact be effectively used, in ways that would generate savings that would provide a decent return on the metering investment.

MIT is developing a high-speed meter capable, at least in some cases, of disaggregating a measured electrical current into components that can be assigned to particular pieces of equipment. This Non-Intrusive Load Monitor (NILM) provides not only time-of-use information at the measurement point (whole building or a major portion of particular interest) but also provides some amount of information about equipment operation, including on/off cycling, an estimate of energy use, and detection and possibly diagnosis of equipment faults. Please see Luo (2001), Luo *et al*. (2002), Norford and Leeb (1996), Norford *et al*. (2000, 2002), Shaw and Leeb (1999), Shaw *et al*. (1998, 2002), and Lee (2003) for more information. The intent of Task 2.1.3 was to include in the selected test buildings one or more for which it would be possible to install a NILM. It was initially planned to select a population of about ten buildings and make use of energy bills in all, supplemented by time-of-use metering in two or three and the NILM in one or two.

A third element in Task 2.1.3 is the use of the NILM for measuring equipment-level performance in sufficient detail to detect faults. This element was not included in the original proposal but it is desirable to offer as much value as possible in a particular research project. For this work, the targeted equipment is roof-top packaged air conditioners. These are widely used and there is considerable recent interest in developing low-cost equipment that can be used to diagnose faults that would compromise cooling output or increase power consumption. A survey of commonly occurring faults in roof-top units and an approach to detecting these faults is presented in Breuker *et al*. (2000).

Based on the three central issues, MIT researchers considered different sets of candidate buildings, as will be discussed in the next section of this report. Note that the three issues do not uniquely specify a single type of building. While it was initially proposed to work in small commercial buildings (retail), it will be shown in the next section of this report that a more suitable population of buildings is K-12 schools. Schools are very different from retail businesses, of course, but there is substantial societal benefit to improving the energy performance of either, or both.

Following the selection of the case-study buildings, this report presents an analysis of school energy consumption. It then provides examples of data collected by submeters and by the NILM. It describes an attempt to determine the benefits of night cooling in one elementary school and documents a series of meetings and presentations about the research. Work on fault detection in roof-top cooling units will be presented in a separate document.

Selection of Buildings for Case Studies

A number of buildings were visited to assess their suitability for field research. These buildings included:

- A community college system in Oakland that consists of three campuses, of which two were visited;
- Three small commercial buildings in East Palo Alto: an auto parts and auto engine-repair store, a grocery, and a funeral home;
- Commercial buildings in the Presidio;
- Four public schools in the West Contra Costa Unified School District (WCCUSD).

The public schools were considered the most suitable for continued research, for several reasons:

- Strong support of an energy-service consultant, who arranged contacts at all sites listed above except the community-college system. She is participating in an effort to improve the energy efficiency of schools in the district and is very helpful in representing MIT's interests to school officials and in describing current energy-upgrade activities.

- PG&E has provided energy-consumption data needed for establishing an internal benchmark (consumption for all schools within the district). This saves MIT the step of needing to collect data to prepare the benchmark and leverages PG&E's efforts.

- Support of school officials for installation of monitoring equipment. It is hard to underestimate the value of this support. Here the issue centers on the second element in the research, as noted above: use of the NILM. Because the NILM is in a development phase, its installation and upkeep is not as streamlined as it will need to be if it is to attract the interest of commercializers. While MIT considers the current status of the NILM to be quite promising, it still requires considerable effort to install and maintain. This effort involves examination of building electrical plans to size current transducers; on-site inspection of building wiring to determine an appropriate location for the meter and to assess difficulties in placing current transducers; hiring of a licensed electrician; and installation of a communications line used to update the programming in the NILM (which runs on a personal computer using the Linux operating system and functions as an Internet site) and to download data. While communications can in principle be provided via an Internet node in an established network, and such a connection has proved to be highly reliable in limited field tests to date, it is often very difficult to obtain an address on an established network. Approvals may be withheld due to security concerns and even when on-site personnel are willing to install a network connection it may in practice be impossible to penetrate existing firewalls. When a network drop cannot be provided, it is necessary to install a DSL line. MIT's experience to date has been that the active cooperation of on-site personnel is essential.

- Interest of school officials in understanding and reducing energy consumption. The first element of this study is an assessment of how energy users could make use of benchmarks. A null result would in principal be interesting: owners or managers of certain types of buildings may feel that they have no time or skill in comparing their energy bills against consumption data for supposedly similar buildings. MIT considers it a better use of CEC-provided research funds if the targeted set of owners or managers in fact does show a willingness to make use of benchmarks. One drawback in using the schools is that there is a single set of personnel responsible for all schools in the district. As a result, the experiment will not include in itself opportunity for managers to talk to each other about energy bills and benchmarks. MIT will attempt to learn about communications among school districts and whether energy consumption is discussed across school-district boundaries.

- Potential near-term extensibility. The consultant who directed MIT to the WCCUSD is working in other public school districts in California. Data analysis techniques, assessments of end-use energy consumption, and conservation strategies that come out of the work at WCCUSD can be readily transferred.

- Opportunity to assess whether the NILM can monitor the performance of rooftop air-conditioning units. One of the schools targeted for metering has this equipment.

- Opportunity to test a load-reduction strategy. Control of loads during peak periods has recently been of particular interest in California. Load control in aggregates of buildings is a task assigned to MIT under Architectural Energy Corporation's prime contract with CEC. In the same school where MIT will monitor a rooftop unit, school officials are already running a fan at night to pre-cool a classroom, in an attempt to reduce on-peak use of the air conditioner. It is worthwhile to monitor the performance of the existing control strategy. Further, it is likely that there is room for improved control of the fan and air conditioner, to minimize overall operating cost.

- Societal benefit. As noted above, public schools, like small commercial buildings in low- or moderate-income neighborhoods (as distinct from more affluent businesses that can afford a wide range of for-hire energy services), can benefit from energy services that would otherwise not be affordable. These services include benefits from participating as test sites in CEC-sponsored research and benefits from the knowledge and technologies generated from this research.

The community college campuses consist of a small number of classroom buildings. As was discovered in a detailed examination of metered data at MIT, it is difficult to match meter accounts with physical space. It appears that there is a similar issue at the community college campuses, where metering accounts and buildings do not match up in on a one-for-one basis. In addition, it would be necessary to construct a benchmark database from other community colleges in California.

The small businesses in East Palo Alto were offered energy audits as part of another program. Owners were willing to take advantage of opportunities to reduce energy bills, but were also very much focused on meeting the needs of their customers. Reaching a larger population (ten buildings, as a target) and working with individual shop owners was considered to be more difficult than working with school officials. MIT has had recent experience in installing and maintaining a NILM in a nearby fast-food restaurant. It would be all but impossible to install NILMs in similar businesses in California without local support.

Buildings in the Presidio are controlled by a Trust and are leased to commercial and residential tenants. The non-profit Presidio Alliance seeks to support occupants and the Trust by identifying energy-efficiency opportunities, including energy monitoring. MIT considered the schools to be more in need of assistance at this time.

West Contra Costa Unified School District

The West Contra Costa Unified School District (WCCUSD) is comprised of sixty-three schools, located in seven cities (El Cerrito, El Sobrante, Hercules, Kensington, Pinole, Richmond, and San Pablo) of Contra Costa County. Table 1 presents the schools types in the WCCUSD.

Table 1 WCCUSD School Types.

School Type	Number of Schools
Elementary Schools	39
Middle Schools	6
High Schools	6
Alternative Schools	10
Special Education Schools	2

Contra Costa County is located on the northeastern San Francisco Bay area (Figure 1). Some climatic and geographic features of the region serviced by the WCCUSD are as follows:

- N37° 54' to N38° 01'N latitude and W122° 17' to W122° 23' longitude.
- Altitude varies from sea level to approximately 400ft.
- The minimum average and maximum average temperatures are 40°F and 76°F respectively. Absolute maximum and minimum recorded temperatures in the last 5 years are 30°F and 106°F.

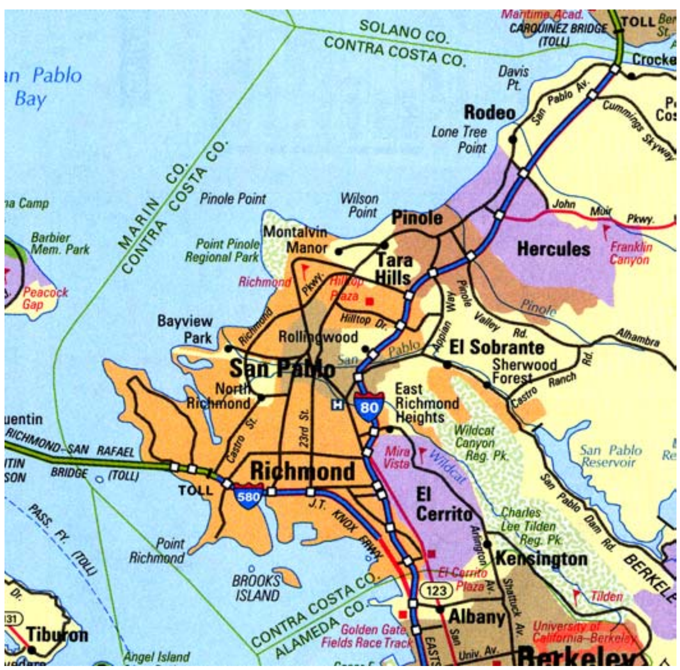

Figure 1 *The Western part of Contra Costa County*

A set of benchmarking tools for school energy consumption was developed, using energy consumption data from schools in the WCCUSD. Data from thirty-nine elementary schools, five middle schools, and five high schools are being used. Alternative and special education schools are not considered in the study. Energy sources for the WCCUSD schools are electricity and natural gas.

Pacific Gas and Electric Company (PG&E) and the WCCUSD facilities office provided annual (1999-2000) electric and gas consumption records (PG&E 2000). Energy figures together with school statistics such as student population and density, school schedules, and physical building features such as construction area and equipment were factors in the benchmarking analysis of energy consumption.

General School Descriptions

Basic school statistics that were factors in our analysis are presented in Table 2. The typical WCCUSD elementary school has a floor area of approximately 43,000 square feet with an average enrollment of 500 students. In comparison, the typical middle school has an area of approximately 122,000 square feet and an enrollment of about 1,000 students, while the average high school has an area of approximately 180,000 square feet and an enrollment of 1,500 students. Downer Elementary School, which has an area of 121,000 square feet with 957 students, is exceptionally large. A graphical comparison of the schools building areas is presented in Figure 2. A comparison of enrollment figures is shown in Figure 3.

Table 2 *Basic School Characteristic Statistics.*

	Construction Area (ft2)			Student Population		
	Elementary	**Middle**	**High**	**Elementary**	**Middle**	**High**
Average	43,690	122,530	185,657	499	1,092	1,537
Median	41,742	125,000	177,762	463	1,088	1,438
Maximum	121,086	158,682	226,510	957	1,283	2,167
Minimum	22,858	78,313	160,915	289	953	1,026
Std. Deviation	15,724	28,673	25,073	149	121	417

It is interesting to note that even though the middle and highs schools are larger than the elementary schools, both in physical size and enrollment, their student densities are similar if not smaller (higher area per capita) than elementary schools. Figure 4 presents the student densities for the WCCUSD schools expressed as floor area per student. A higher number indicates a lower density and vice versa.

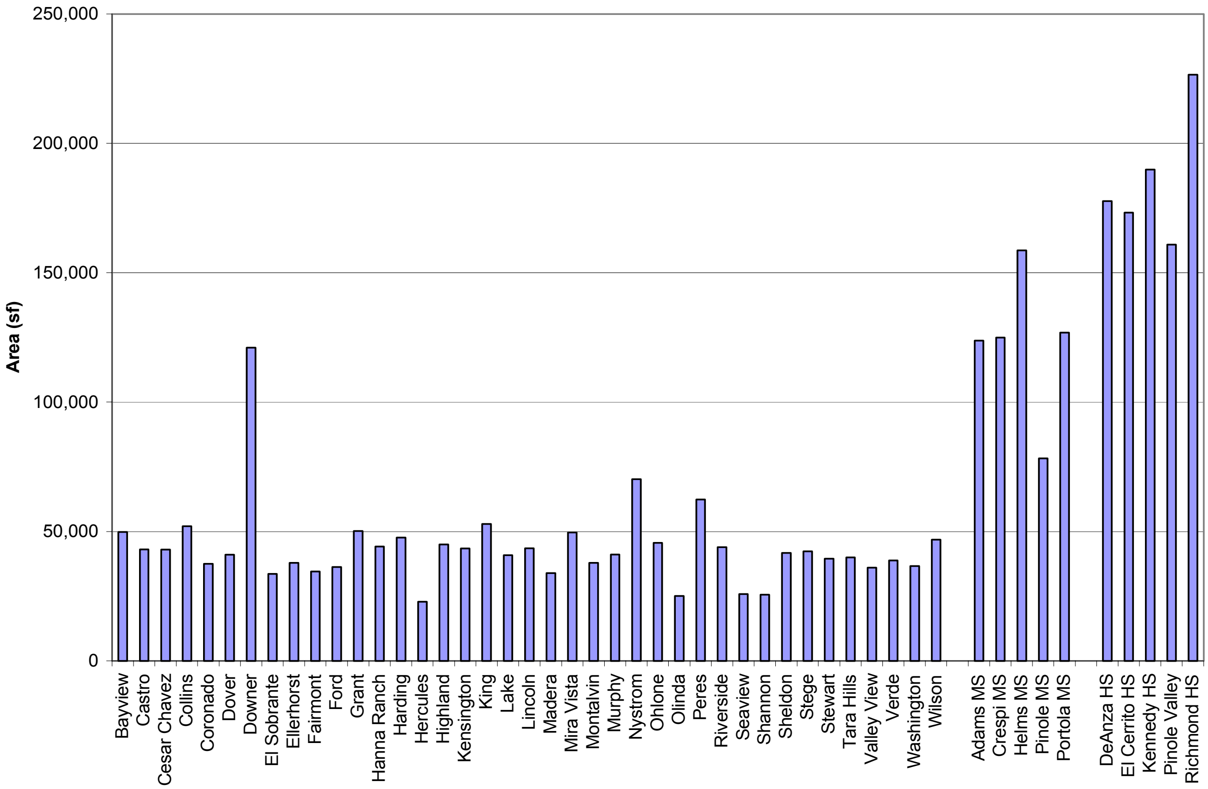

Figure 2 *WCCUSD School Building Areas.*

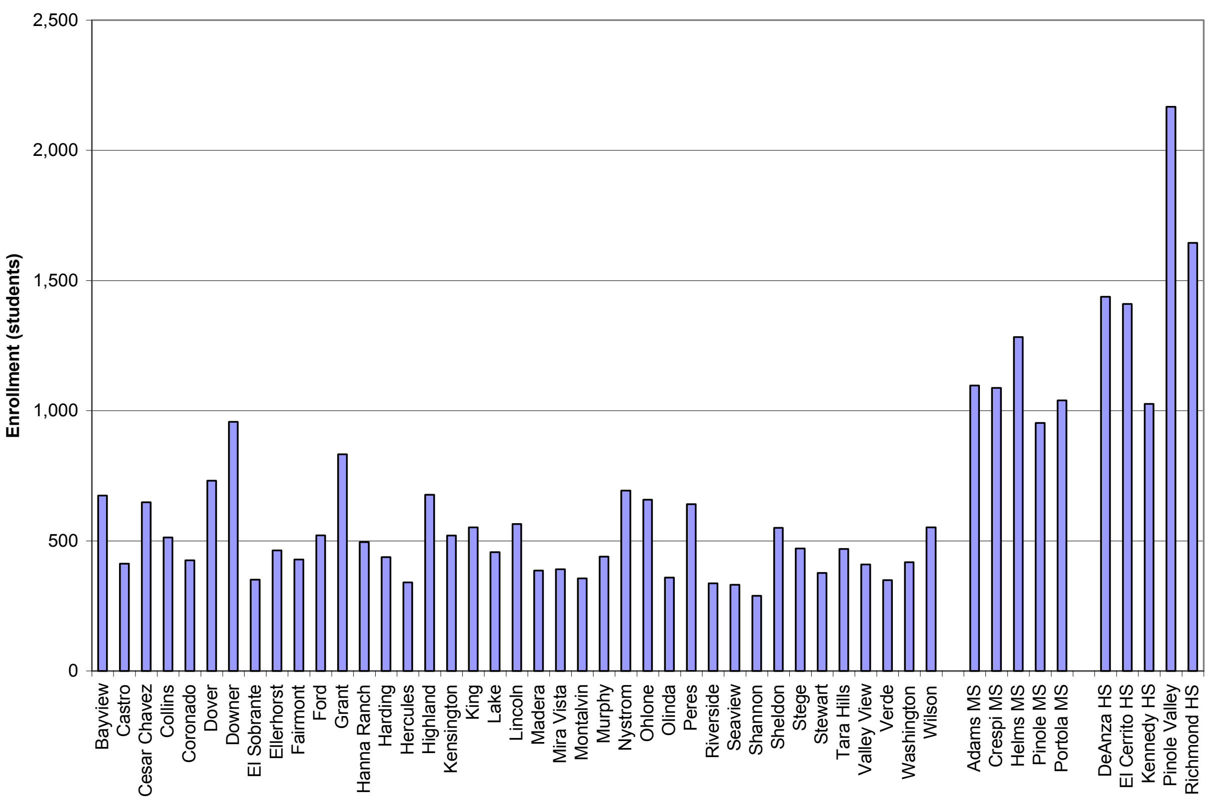

Figure 3 *WCCUSD School Enrollment.*

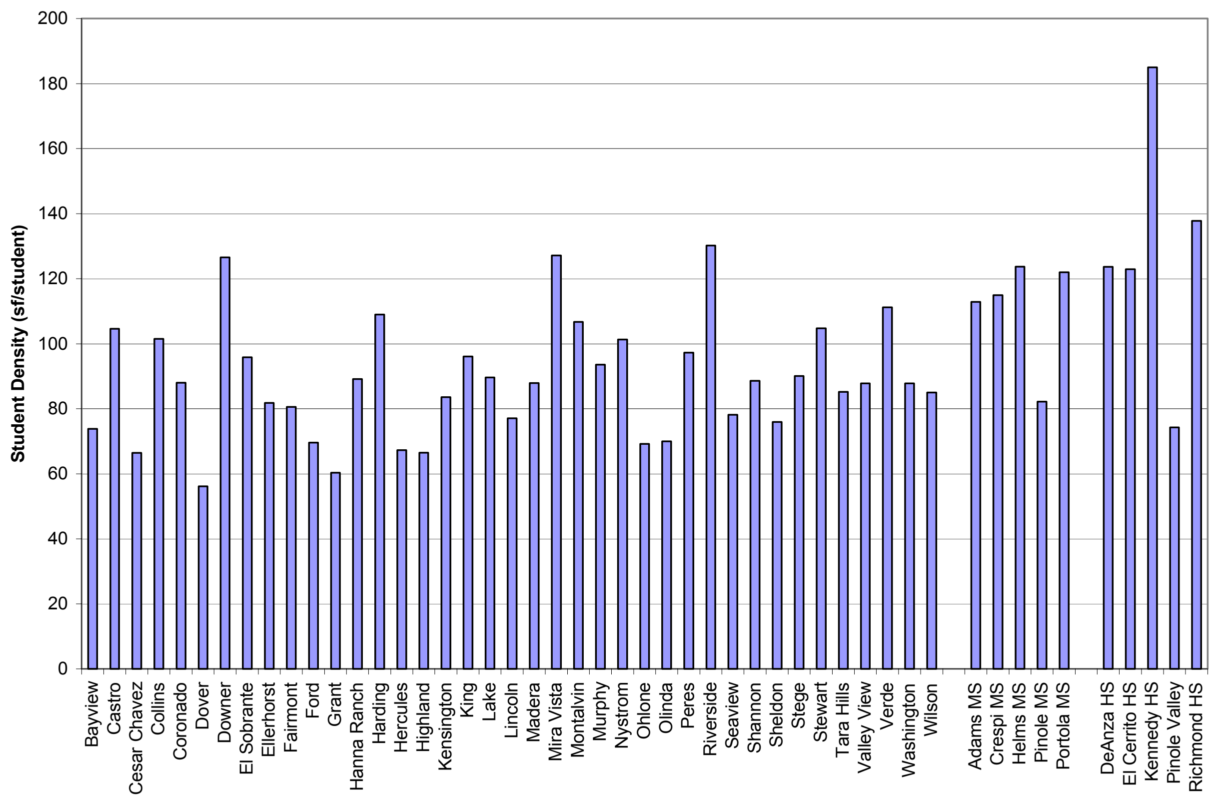

Figure 4 *WCCUSD School Student Density.*

Annual Energy Consumption Analysis

Energy consumption analysis for the schools was performed for both sources of energy in the schools, natural gas and electricity, and their combined total in terms of absolute annual values (energy/year) as well as in relative terms (energy/area and energy/student). Additionally, the ENERGY STAR® For Schools benchmarking tools developed by the Environmental Protection Agency (EPA) and the US Department of Energy (DOE) and available on the World Wide Web (http://www.energystar.gov) were used to rate the schools in order to compare the results of the energy analysis performed on the school data.

Absolute Energy Consumption

Absolute site energy consumption (Figure 5) of the middle and high schools is greater than the energy consumption of elementary schools, with the exception of *Downer Elementary*, which has energy consumption greater than the middle schools and similar to the high schools. The percentage contribution of the two energy sources utilized in the schools is presented in Figure 6. The basic statistics for the electric energy contribution to the total school energy utilization are presented in Table 3.

Elementary schools rely mainly on natural gas as the energy source, with the exception of *Ohlone Elementary* whose main source of energy (96%) is electricity. The extremely high ratio of electricity to natural gas utilization at *Ohlone* is due to the school's being completely air-conditioned, and the equipment operating on electricity both during the cooling and heating season. Other elementary schools with a high ratio of electricity to natural gas use are at least partially air-conditioned, but the heating equipment is gas fired.

The percentage of electric energy used at the middle schools is lower than in the elementary and high schools. The low ratio of electricity to natural gas use at the middle schools can be explained by the fact that they are not air-conditioned, with the exception of *Pinole Middle* that has partial air conditioning, and heating is provided by natural gas.

Table 3 *Schools Electricity Contribution Statistics.*

	Elementary	Middle	High	All
Average	44%	36%	52%	44%
Median	40%	30%	50%	40%
Maximum	96%	61%	71%	96%
Minimum	18%	27%	32%	18%
Std. Dev.	17%	14%	14%	17%

The fraction of electric energy used at the WCCUSD high schools is similar to the fraction of natural gas energy utilized. The electricity fraction is greater than in the middle and elementary schools as a group. Further knowledge of the high school physical equipment is needed in order to provide a good explanation for the approximately equal amounts of electric and gas used.

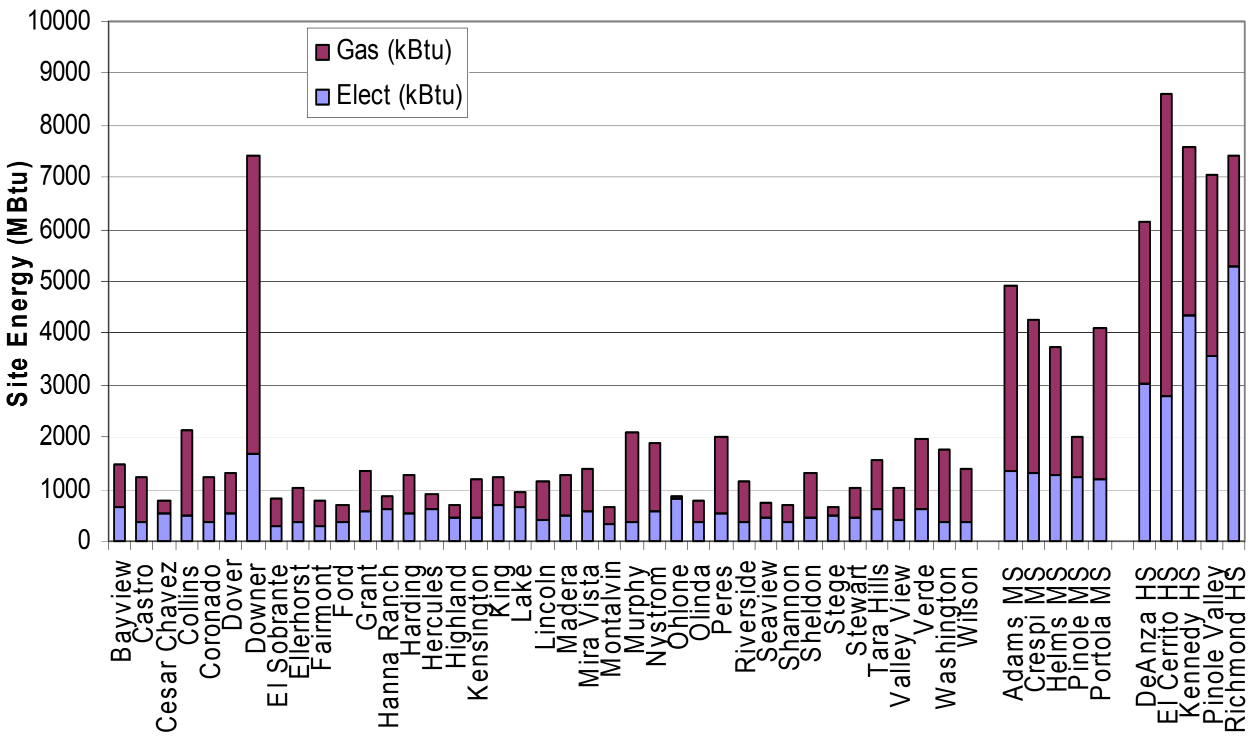

Figure 5 *WCCUSD Schools Absolute Energy Consumption.*

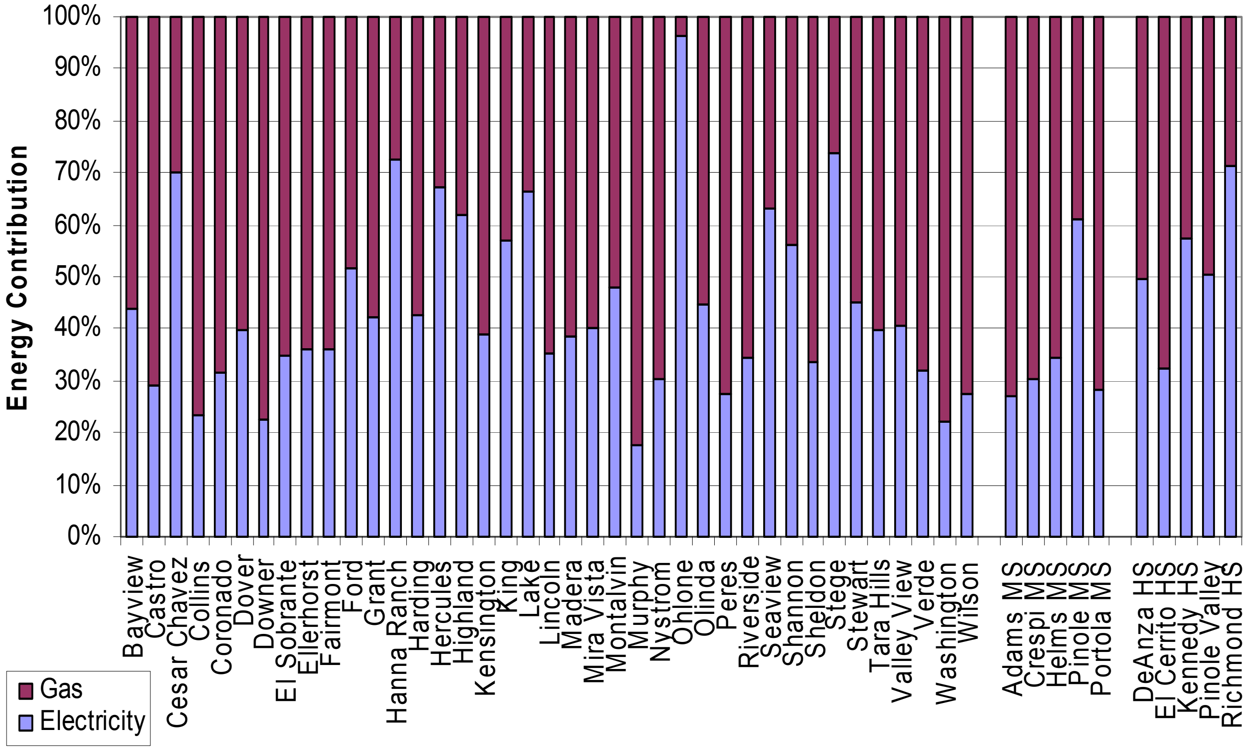

Figure 6 *Percentage Energy Contributions of Electricity and Natural Gas.*

To gain an additional perspective to the problem, the energy cost is also analyzed both in absolute and relative terms. Energy cost for the WCCUSD schools is presented in Figure 7. It can be seen that the total energy cost follows the same trend as the total energy consumption at the schools. Energy cost is the greatest for the high schools, followed by the middle and elementary schools.

The cost contribution for the different energy sources, however, does not follow the energy utilization contribution trends presented previously. It can be seen in Figure 8, and in the statistics presented in Table 4, that even though electricity accounts for less than 45% of the total energy use at the schools, in economic terms it accounts for more than 77% of the total annual cost of energy in the district schools. Electricity has a higher cost per site energy unit than natural gas, which explains the greater contribution of electricity to the energy cost in the schools.

Table 4 *Schools Electricity Cost Contribution Statistics*

	Elementary	Middle	High	All
Average	76%	72%	82%	77%
Median	77%	66%	83%	77%
Maximum	99%	88%	93%	99%
Minimum	51%	62%	67%	51%
Std. Dev.	11%	11%	9%	11%

The energy consumption and cost data for the studied schools are presented in Appendix B.

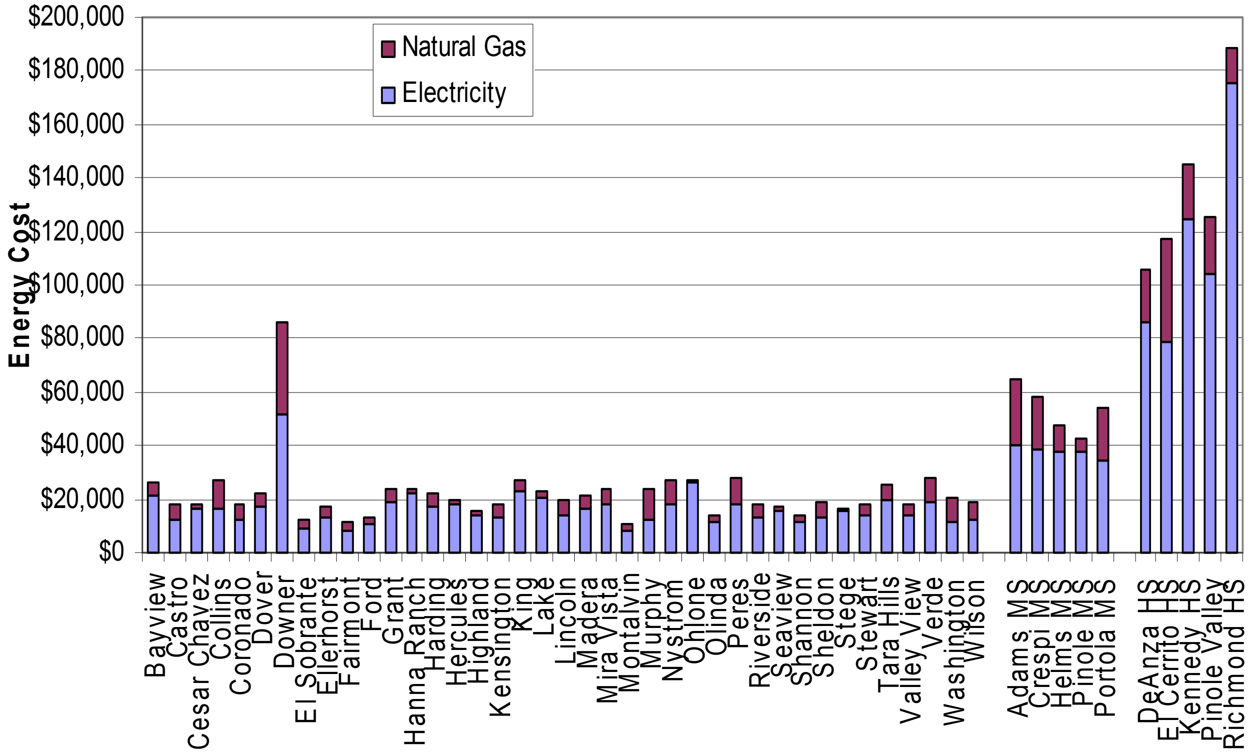

***Figure** 7 WCCUSD Schools Absolute Energy Consumption Cost.*

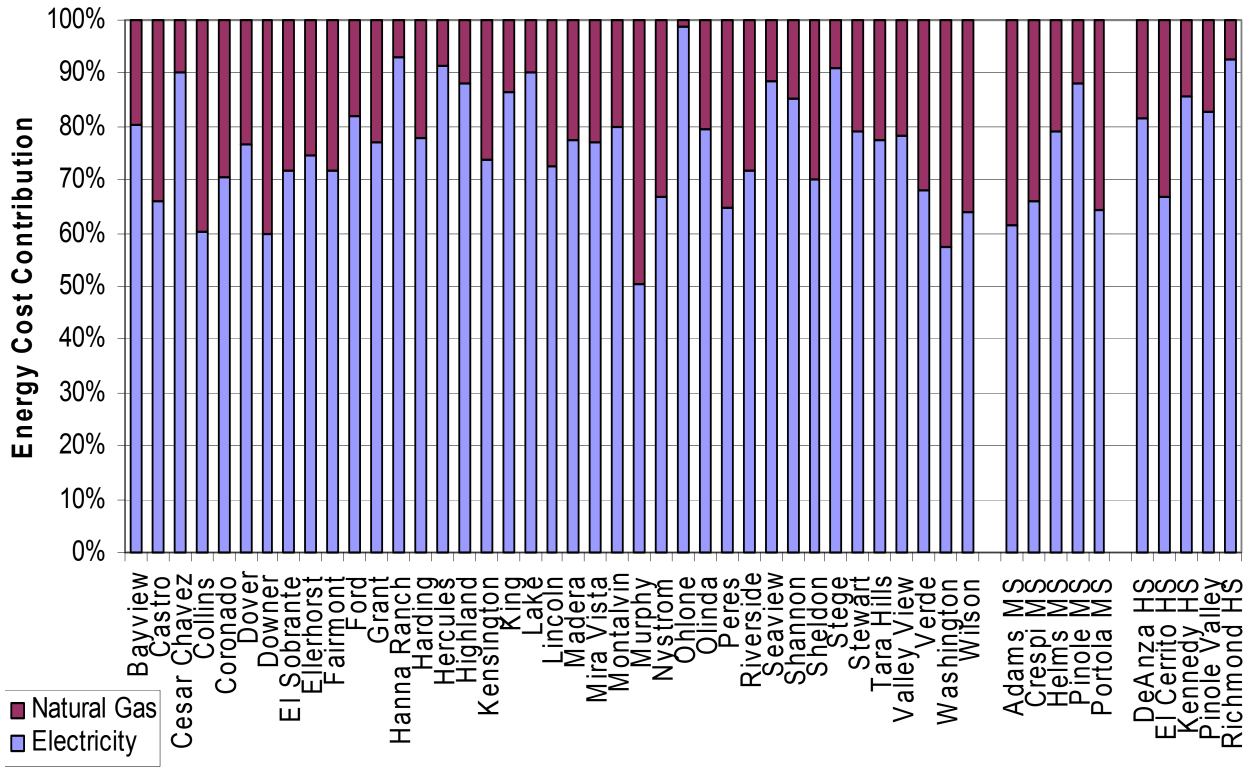

***Figure 8** Percentage Energy Cost Contribution for Electricity and Natural Gas.*

Relative Energy Consumption

Absolute energy consumption figures provide a good indicator of a building's efficiency when compared to similar buildings. However, a better indicator of the efficiency of a building is the energy consumption per unit of reference. Similarly, a better indicator of the cost-effectiveness of a building is the energy cost per unit of reference. In our particular case, the units of reference used are units of area (ft^2) and student population. Appendix C shows the school energy consumption and cost per student, while Appendix D presents the school energy consumption and cost per unit of area. These indicators permit a comparison of the performance of the schools independently of their size or student population.

The energy use per student and energy cost per student for the WCCUSD schools are presented in Figure 9 and Figure 10 respectively on the next page. Statistics for the total energy and cost per student are presented in Table 5.

High schools, on average, consume more energy per student than middle and elementary schools. Also the energy cost per student is larger for the high schools.

Table 5 *School Energy Statistics per Student.*

	Elementary Schools		Middle Schools		High Schools		All Schools	
	kBtu/pers	$/pers	kBtu/pers	$/pers	kBtu/pers	$/pers	kBtu/pers	$/pers
Average	2682	$44.03	3470	$49.23	5106	$94.13	3010	$49.67
Median	2363	$43.64	3926	$51.83	4518	$83.27	2610	$47.26
Maximum	7753	$90.12	4492	$59.14	7398	$141.31	7753	$141.31
Minimum	1040	$22.80	2086	$37.08	3247	$57.74	1040	$22.80
St. Dev.	1282	$13.84	967	$8.48	1640	$33.65	1473	$22.00

Energy and energy cost per unit floor area statistics are presented in Table 6. Figure 11 shows graphically the energy per unit area consumed at the schools while Figure 12 presents the energy cost per unit area.

Table 6 *School Energy Statistics per Unit Area of Construction.*

	Elementary Schools		Middle Schools		High Schools		All Schools	
	kBtu/ft^2	$/ ft^2	kBtu/ ft^2	$/ ft^2	kBtu/ ft^2	$/ ft^2	kBtu/ ft^2	$/ ft^2
Average	29.6	$0.50	31.0	$0.45	40.1	$0.73	30.9	$0.52
Median	27.3	$0.48	32.4	$0.46	40.0	$0.76	28.8	$0.50
Maximum	61.3	$0.88	39.8	$0.55	49.7	$0.83	61.3	$0.88
Minimum	15.6	$0.27	23.4	$0.30	32.8	$0.59	15.6	$0.27
St. Dev.	10.1	$0.12	6.7	$0.10	6.9	$0.09	9.9	$0.14

When efficiency is measured using energy per unit area (energy intensity), we find that elementary and middle schools have approximately the same average intensity while high schools present higher energy intensity. However, the schools with the highest energy intensities are not high schools but elementary schools. Energy cost per unit area is approximately the same for elementary and middle schools but bigger for the high schools.

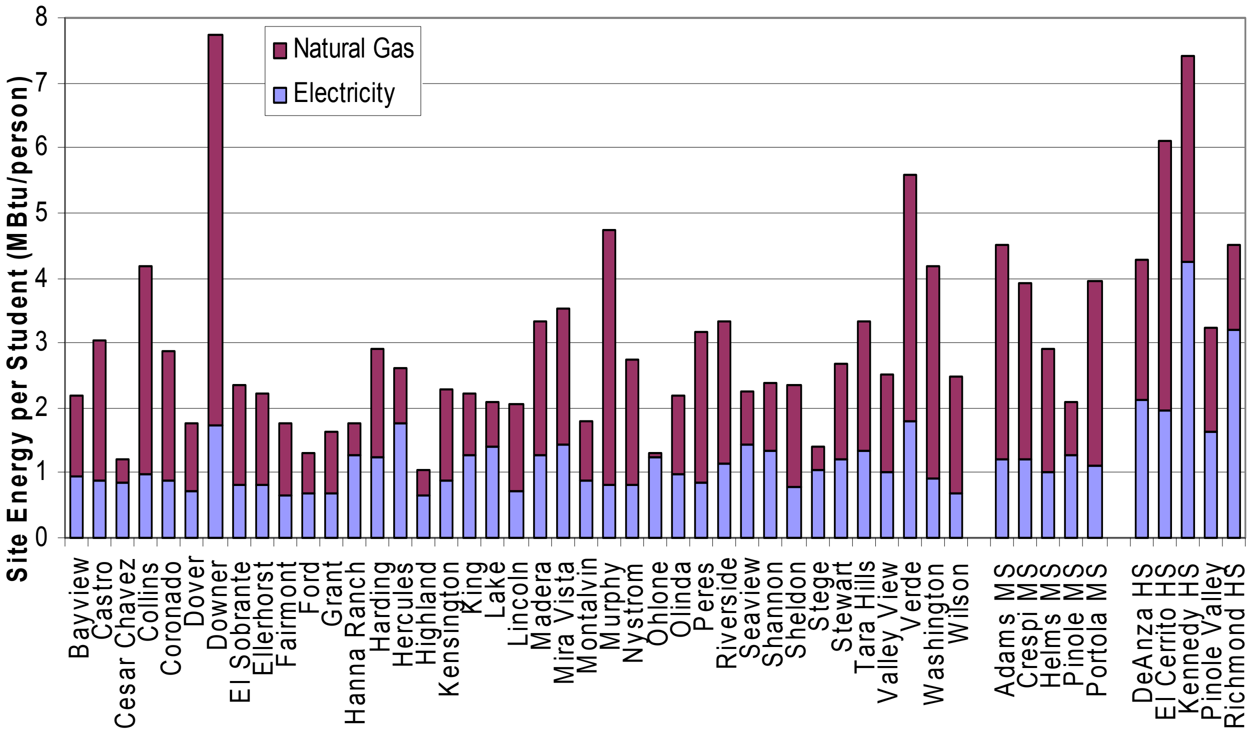

Figure 9 *WCCUSD Schools Site Energy Consumption per Student.*

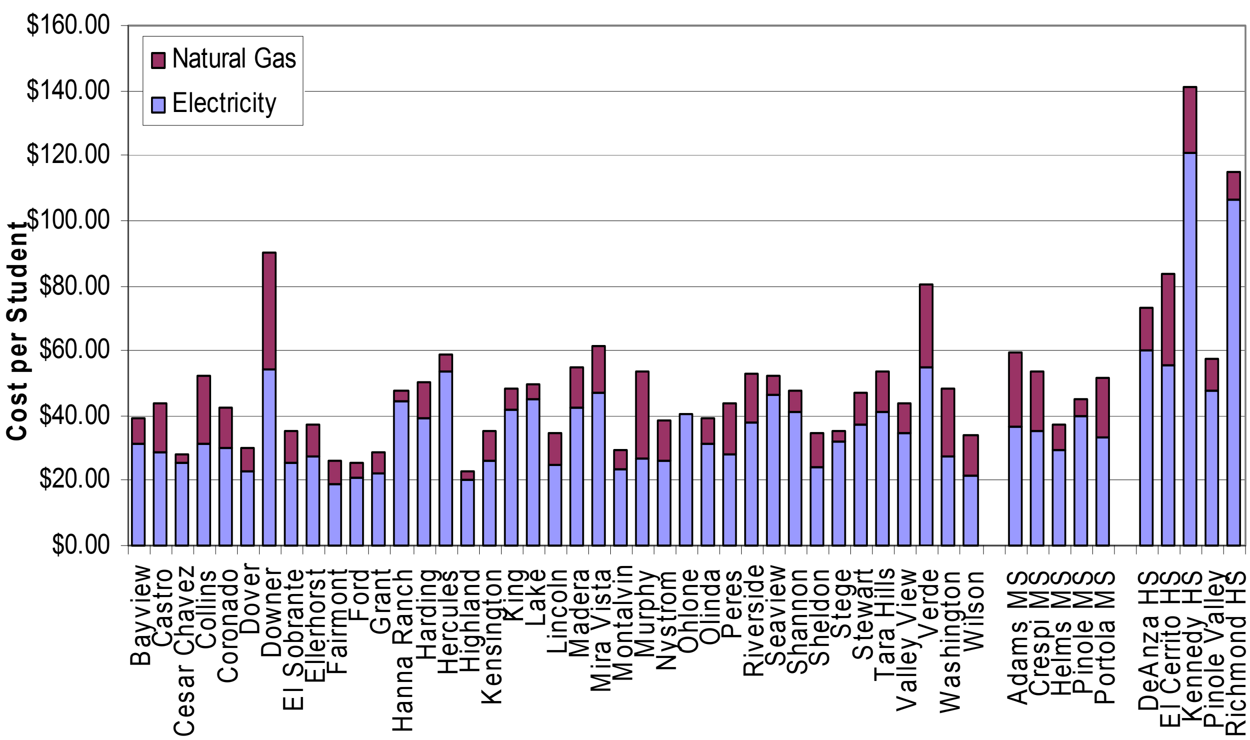

Figure 10 *WCCUSD Schools Energy Cost per Student.*

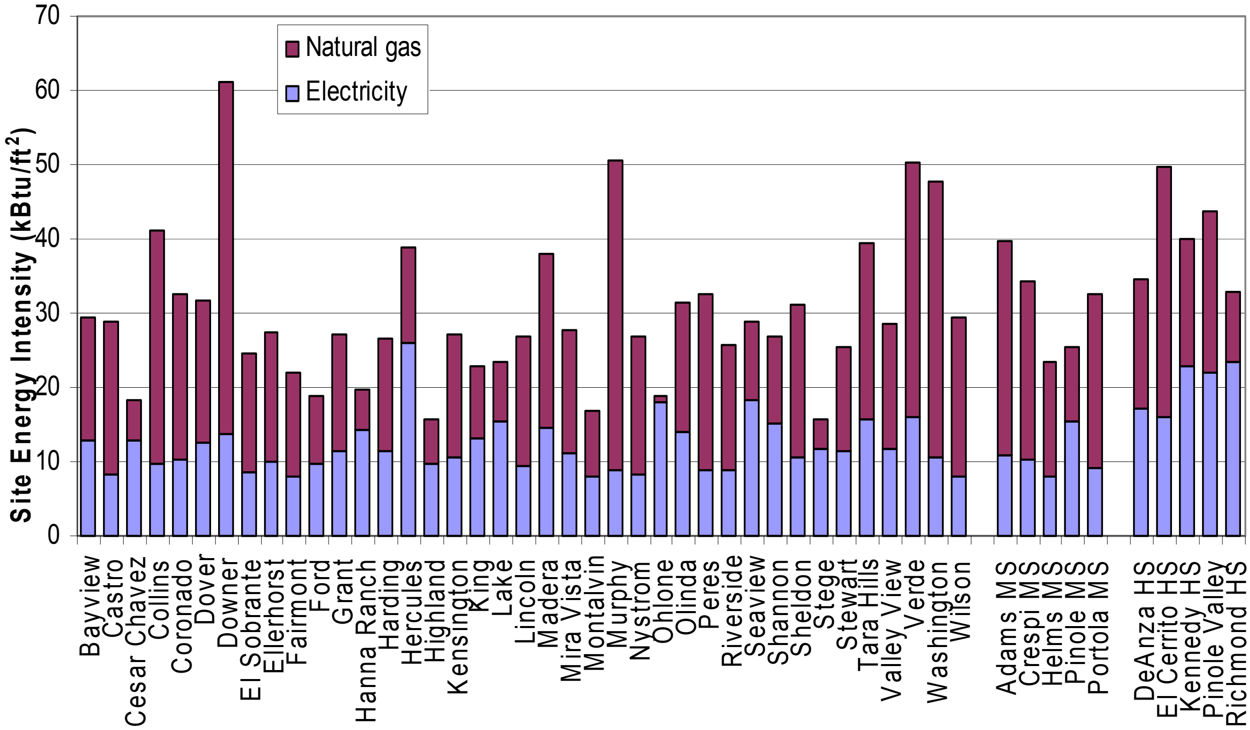

Figure 11 *WCCUSD Schools Site Energy Consumption per Unit Area.*

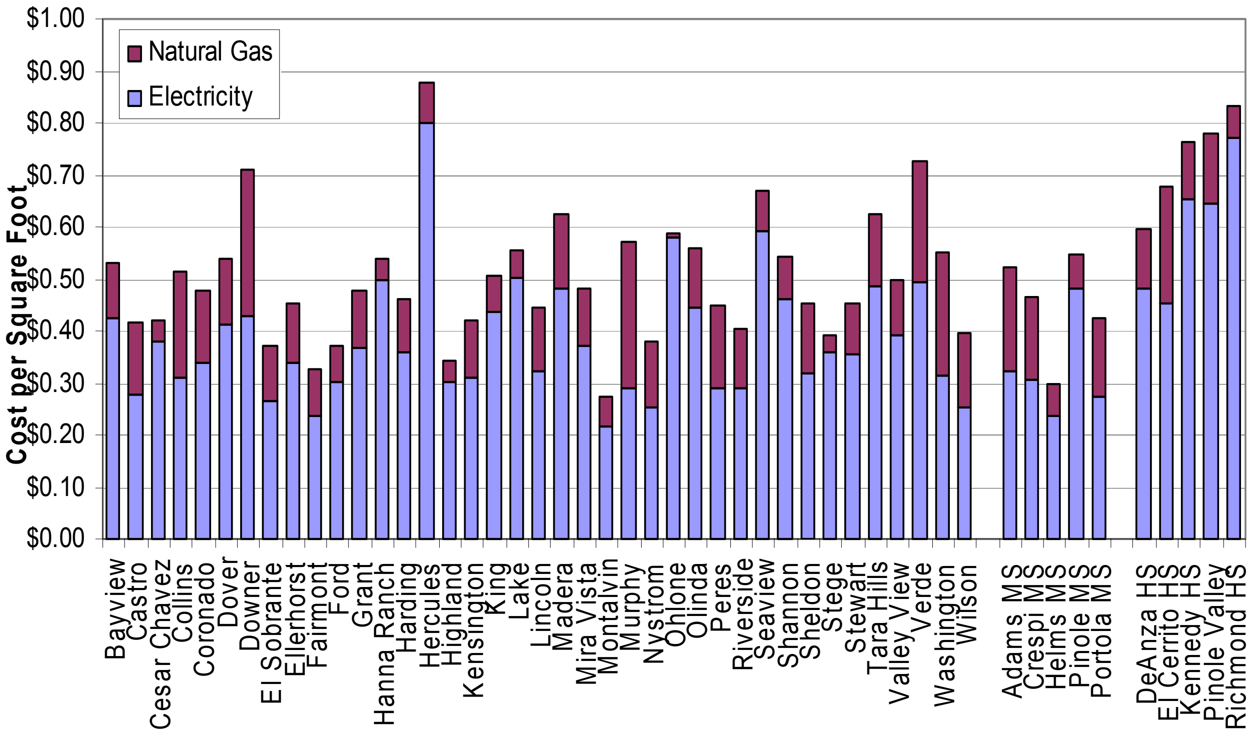

Figure 12 *WCCUSD School Energy Cost per Unit Area.*

The four relative indicators presented show, in general, that high schools as a group consume more energy than elementary and middle schools. One possible explanation might the different hours of operation of the schools. In order to consider the times of operation, the relative energy use indicators were normalized by the number of hours of class per week (Appendix E).

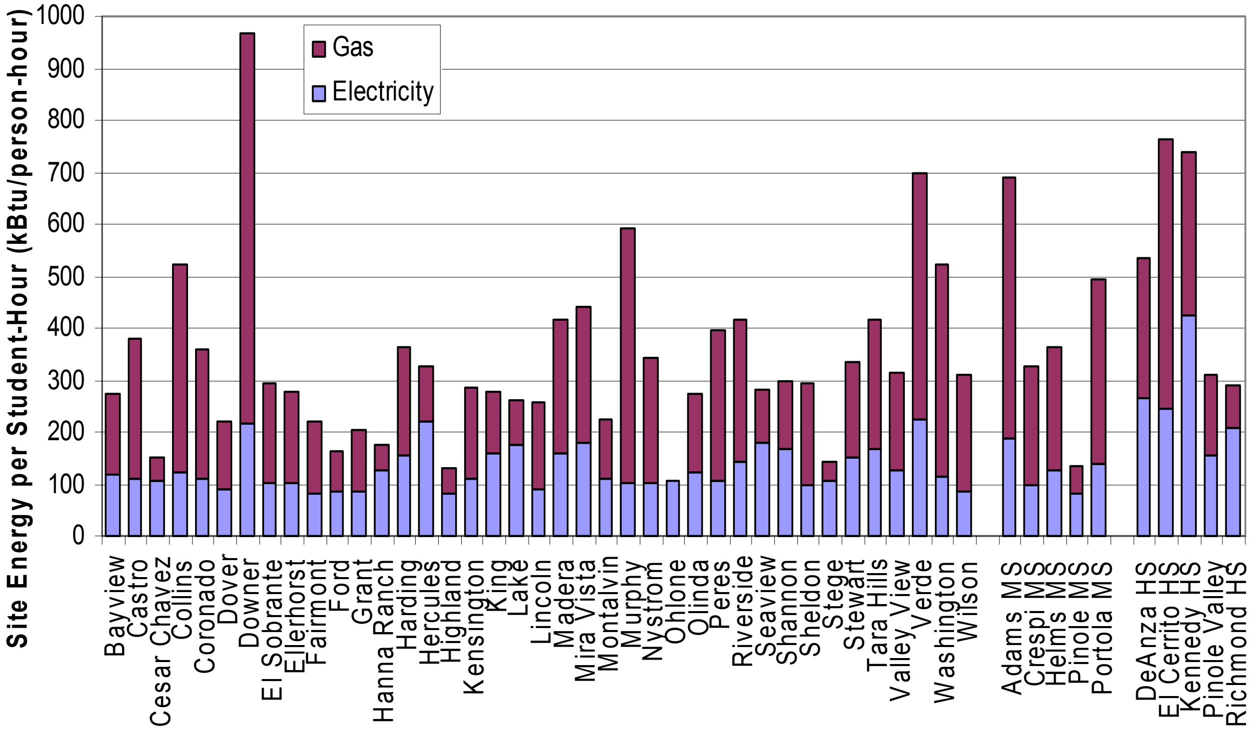

Figure 13 *WCCUSD Site Energy per Student Normalized by Hours of Operation.*

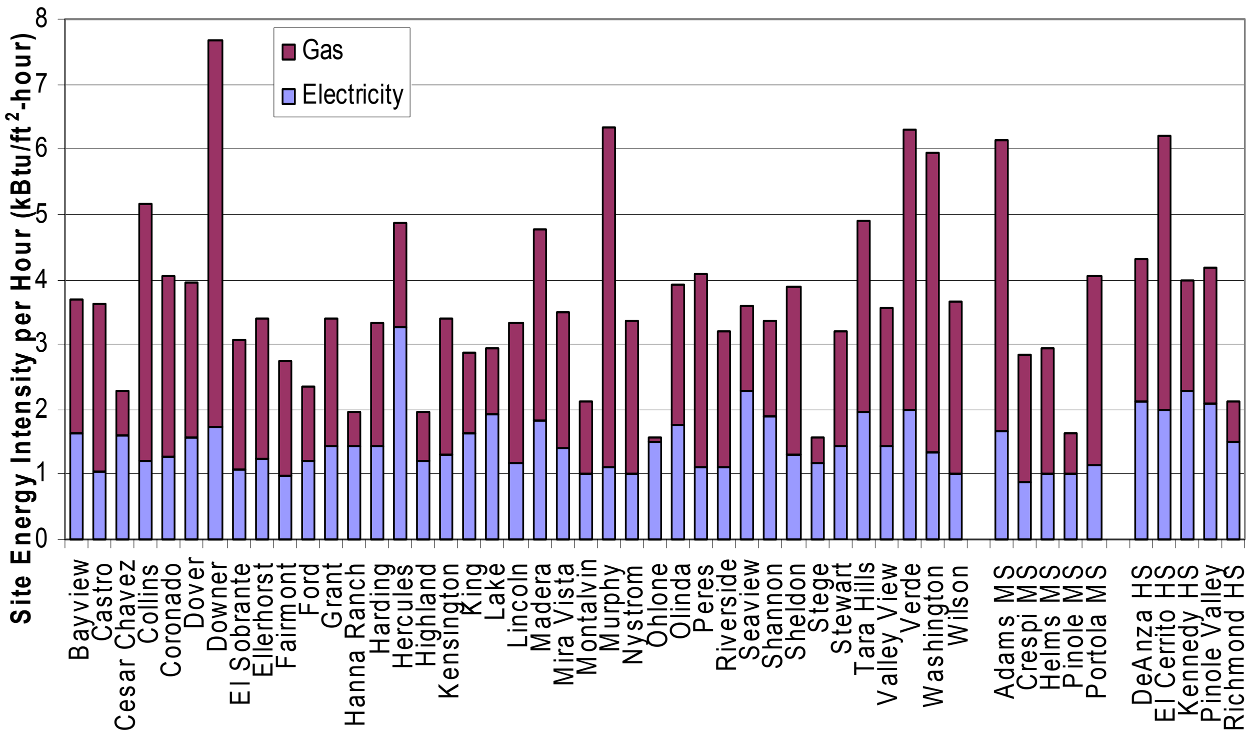

Figure 14 *WCCUSD Site Energy Intensity Normalized per Hours of Operation.*

It can be seen from the previous figures and Table 7 below, that when the relative energy consumptions are normalized by the hours of operation of the schools, the high schools still consume on average more energy than middle and elementary schools. However, some of the high schools consume less than the average of the elementary and middle schools.

***Table** 7 School Relative Energy Statistics per Hour of Operation.*

	Elementary Schools		Middle Schools		High Schools		All Schools	
kBtu per	**ft^2-hr**	**person-hr**	**ft^2-hr**	**person-hr**	**ft^2-hr**	**person-hr**	**ft^2-hr**	**person-hr**
Average	3.66	332	3.52	402	4.16	527	3.70	359
Median	3.41	295	2.92	361	4.16	533	3.48	312
Maximum	7.66	969	6.12	691	6.21	763	7.66	969
Minimum	1.56	108	1.64	135	2.12	291	1.56	108
St. Dev.	1.32	164	1.69	207	1.45	226	1.35	181

THE SCHOOL RANKING INDEX

The school energy consumption and cost were analyzed using absolute and relative indicators. The use of multiple indicators led to multiple school rankings, each one different (Appendix F). A ranking index was defined in order to present the results obtained from the different indicators using a single figure. The ranking index number was computed by taking the average of the rank positions of each school under each indicator. The indicators used were: site energy consumption and cost; site energy and cost per student; site energy intensity and cost per unit floor area; energy per student-hour of operation; and energy intensity per hour of operation. Figure 15 presents the rank index value obtained by the different schools in the district. Figure 16 shows the schools in ranked order.

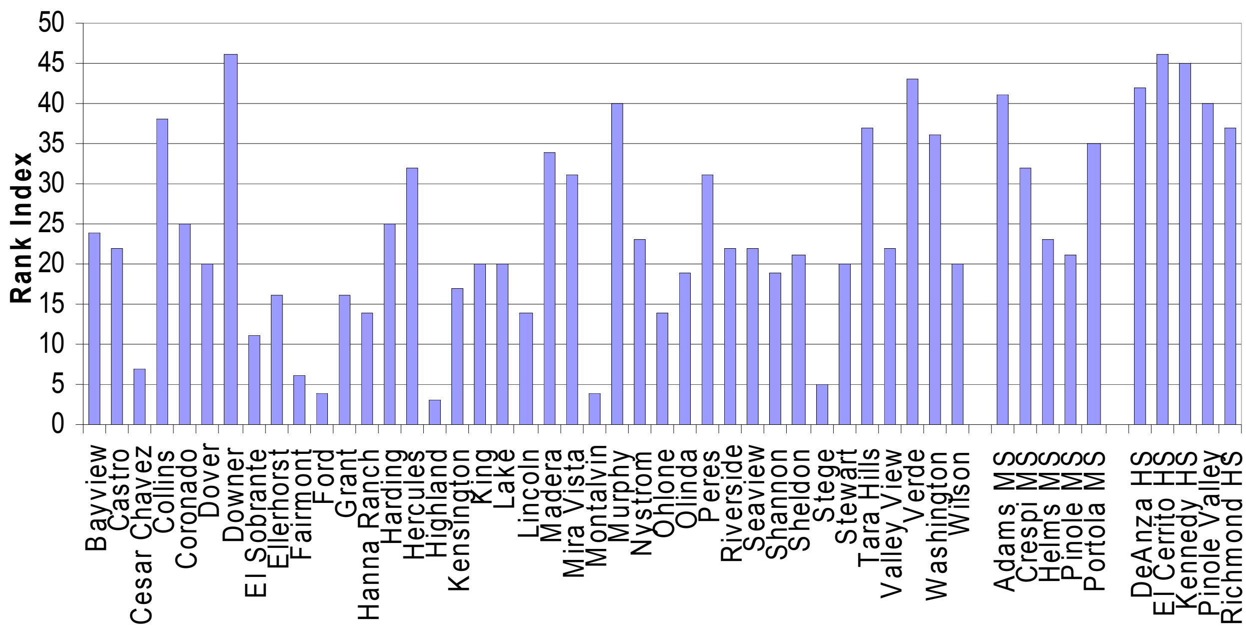

***Figure 15** Schools Rank Index Results.*

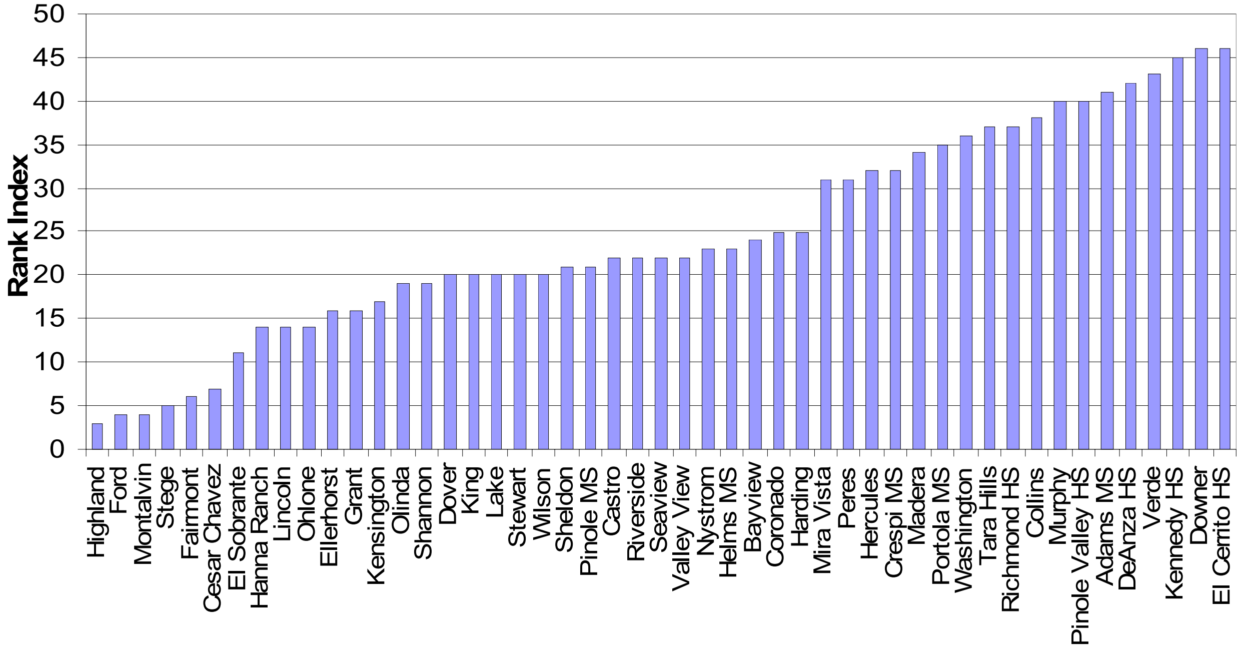

Figure 16 *School Ranking Results.*

ENERGY STAR® Benchmarking of the Schools

The EPA and the DOE have established the ENERGY STAR® criteria (http://www.energystar.gov) for commercial and K-12 school buildings to promote energy efficiency and environmental conservation. The basis for the criteria is the benchmarking of building energy consumption on a 1 to 100 scale. Buildings that earn a benchmarking score of 75 or greater are considered to be among the top 25 percent nationwide in terms of energy performance, and are eligible to apply for the ENERGY STAR label for buildings if they also conform to industry standards of indoor environment.

The ENERGY STAR model is based on source consumption and building characteristics data for K-12 schools obtained from the 1995 EIA Commercial Buildings Expenditures and Consumption Survey (1995 CBECS). The score is computed based on a comparison of the actual source energy use intensity (EUI) of the building and a predicted source EUI based on the regression analysis of the CBECS data.

The ENERGY STAR program computes the actual source EUI from the site EUI based on the type of energy (gas, electric, oil, etc.) used by the building. The predicted source EUI is a function of the following input variables: building area and its natural logarithm, hours of occupation per week, months used, student population, percentage of mechanical cooling, presence of cooking facilities, and heating degree days. The user input variables to the program are building energy consumption records for the different energy sources as well as the building location and the physical and operational characteristics. The program obtains the weather information based on the building geographic location and the dates of the energy records provided.

The ENERGY STAR scores were computed for the 49 schools. Actual annual gas and electric records, building area, student population, and cooking facilities data were used. The hours of operation (8 hours per day) and percentage of mechanical cooling (*italic values* in Appendix A, estimates by the school's maintenance staff) were assumed for most of the elementary schools, while actual values were used for the middle and high schools.

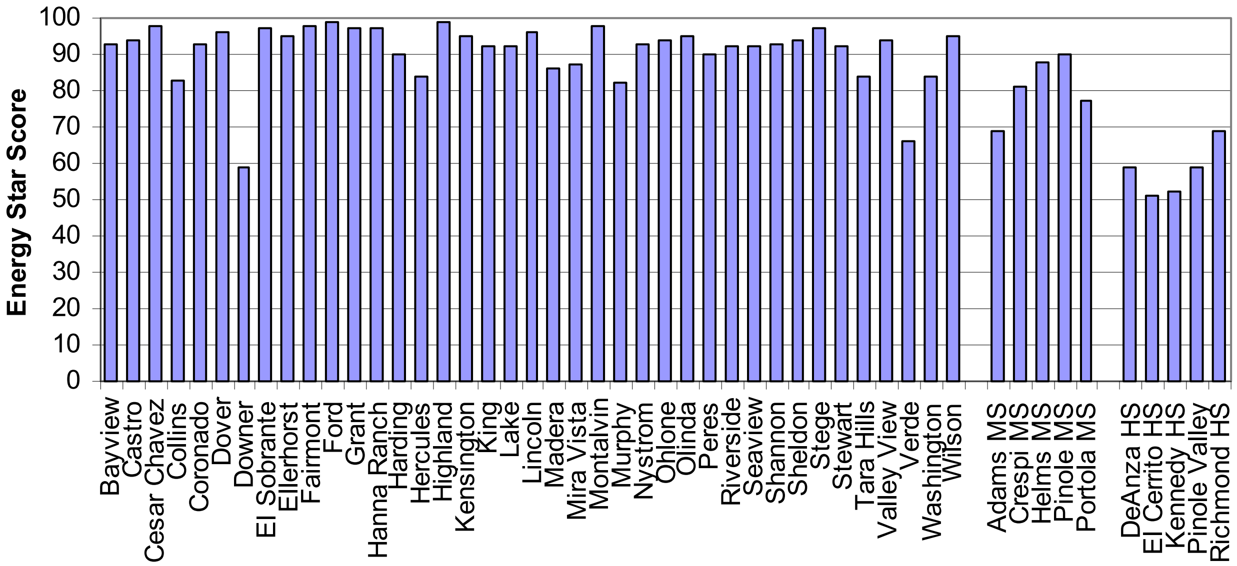

Figure 17 *WCCUSD ENERGY STAR® Scores*

Scores for the schools varied greatly, mainly based on the school type. Figure 17 presents the scores obtained using the school data. None of the high schools obtained a score above 75, while only one of the middle schools and two of the high schools did not score above 75. Table 8 presents the school score statistics. As seen in the graph and the table, the high schools scored the worst, the elementary schools scored the best, and the middle schools scored in between.

Table 8 *Energy Star Scores Statistics*

	Elementary	Middle	High	All
Average	91.2	81.0	58.0	86.7
Median	93.0	81.0	59.0	92.0
Maximum	99.0	90.0	99.0	99.0
Minimum	59.0	69.0	51.0	51.0
Std. Deviation	8.2	8.5	7.2	13.0

The figures below present the comparison between the ENERGY STAR Score and the efficiency indicators used to categorize the schools' energy performance. It can be observed that in general the ENERGY STAR Score decreases as the EUI and the energy use per student increase. A similar relation is observed between the scores and the energy cost, albeit less pronounced because energy cost is related to the energy consumption and the ratio between the different energy sources, and also because the price per energy unit varies from one location to another.

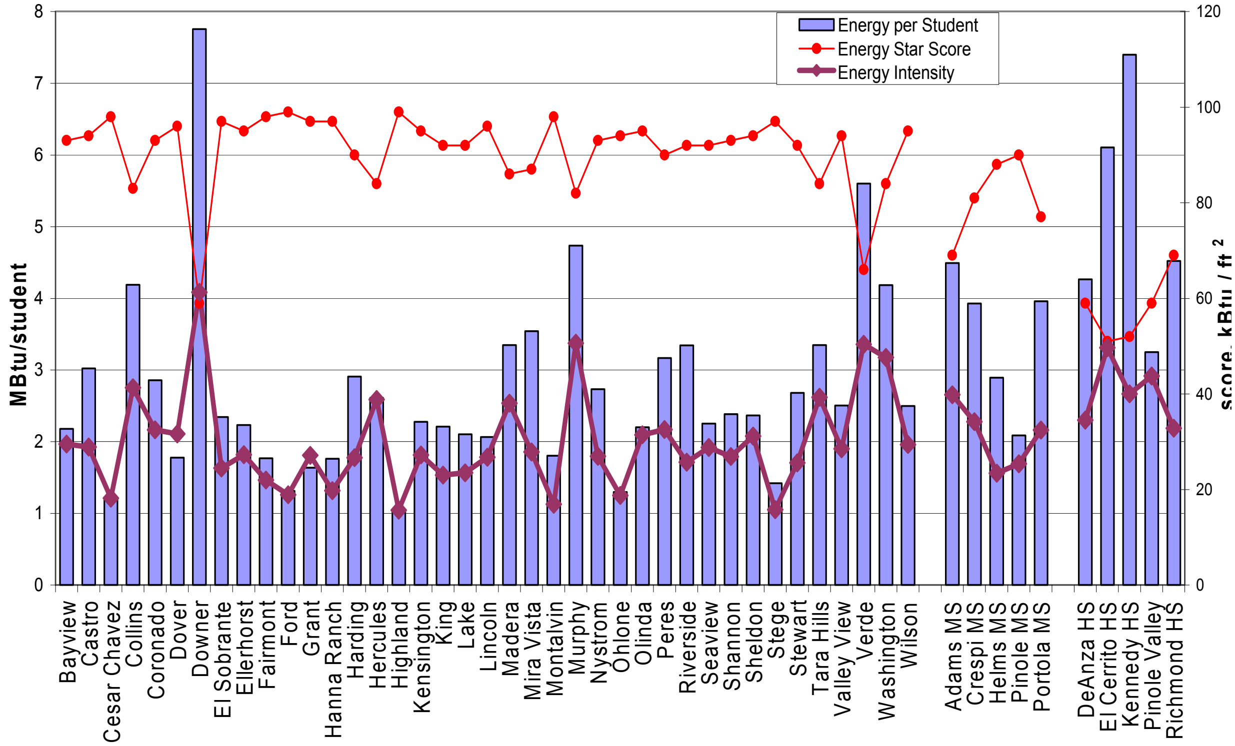

Figure 18 *WCCUSD School Energy Densities and Energy Star Score Comparison*

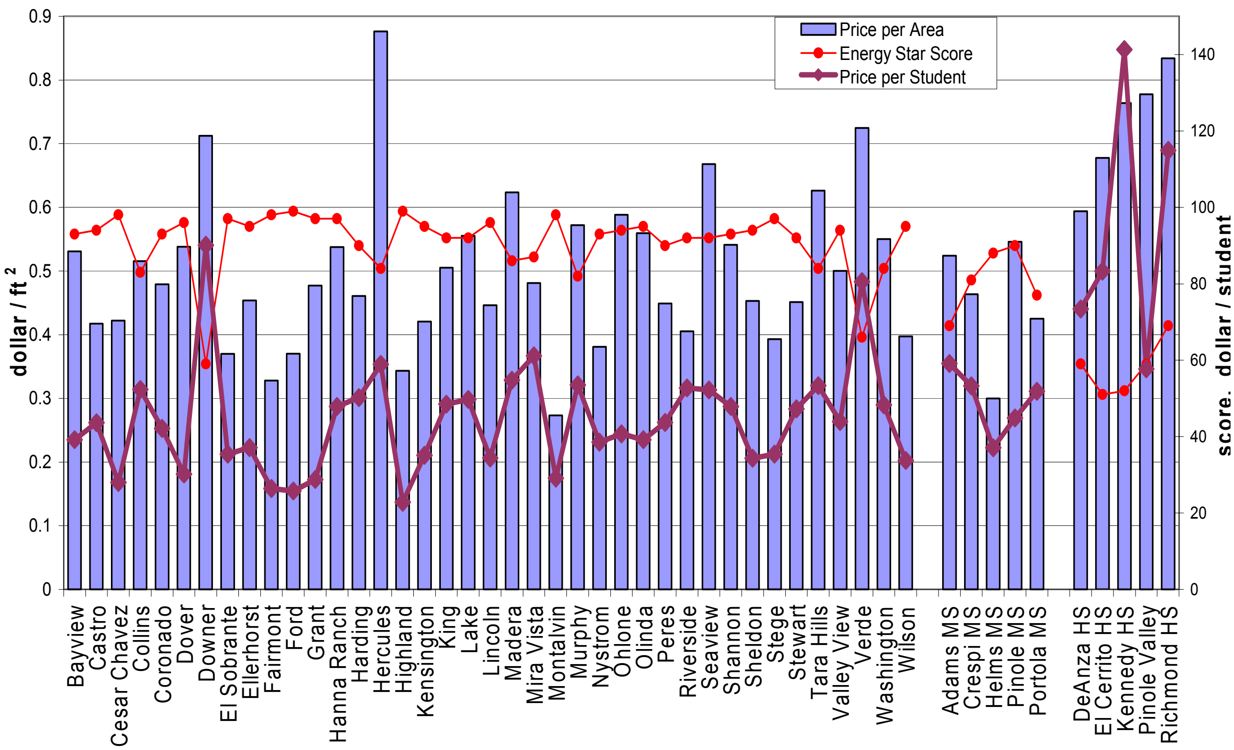

Figure 19 *WCCUSD Schools Energy Cost Densities and Energy Star Score Comparison*

School Energy Benchmarking Results and Discussion

The energy consumption data for 49 schools (39 elementary, 5 middle, and 5 high schools) of the West Contra Costa Unified School District were analyzed in order to benchmark their performance. Two sources of energy, electricity and natural gas, are used primarily at the WCCUSD, and their cost and consumption values were compared in absolute and relative terms. Relative figures, consumption or cost per unit of reference, were found to be better indicators of the schools' performances. Finally, a ranking index was defined based on the results obtained from the absolute and relative indicator comparisons in order to rank the schools energy use performance using a single figure. Schools' energetic performances were also benchmarked using the building energy benchmarking tool ENERGY STAR® developed by the EPA and DOE. The results of the energy consumption analysis are summarized in the following paragraphs.

- In terms of energy per student used, the worst school was *Downer Elementary* followed by *Kennedy High* and *El Cerrito High*. The best schools were *Highland Elementary*, *Cesar Chavez* and *Ohlone* Elementary schools.
- The least cost-effective schools in term of dollars per student spent on energy were *Kennedy High*, *Richmond High* and *Downer Elementary*. The most cost effective were *Highland*, *Ford* and *Fairmont* Elementary schools.
- Considering the schools' energy intensity, the worst performing schools were *Downer*, *Murphy* and *Verde* elementary schools. The best performing schools were *Highland*, *Stege* and *Montalvin* elementary schools.
- From the cost per unit area point of view, the least cost-effective schools were *Hercules Elementary, Richmond High* and *Pinole Valley High*. *Downer Elementary* would be the sixth worst performer. The most cost-effective schools were *Montalvin, Helms* and *Fairmont* elementary schools.
- From the ENERGY STAR® results, the worst scores were those of the high schools and *Downer Elementary*.
- The worst performing schools, based on the ranking index, are *De Anza High, Verde Elementary, Kennedy High, El Cerrito High,* and *Downer Elementary* School*s.* The best performing schools are *Highland, Ford, Montalvin, Stege, and Fairmont* Elementary Schools.

The benchmarking analysis performed on the energy consumption of the WCCUSD schools identified the worst and best energy users, therefore identifying schools that would benefit the most from implementing energy conservation measures. However, this analysis was based only on the annual consumption figures and did not take into account the weather effects on the schools energy consumption. Due to the different microclimates existent in the western part of the Contra Costa County, not all the schools in the district are subject to the same environmental conditions. A better benchmarking of the schools energy consumption will be achieved once the energy data are normalized with weather data from the various microclimates in the district.

School Power and Energy Monitoring

Annual energy consumption records can be used as general indicators of the energy efficiency of a building. However, these records do not present the daily energy consumption patterns in a building, which provide a better insight on the building energy utilization. Daily consumption patterns present when energy is used in a building, and could be used to develop changes in the energy consumption that could result in lower energy utilization or reduced energy costs by shifting the times of consumption.

Non-Intrusive Load Monitoring machines (NILM) were installed at two schools in the WCCUSD: Hanna Ranch Elementary School and Pinole Middle School. The NILM machines record electrical power consumption at the supply point of an electrical distribution panel. Two NILM machines were installed at each school, one monitoring whole school electricity consumption, and the other monitoring the electricity consumption at a secondary electrical distribution panel serving a group of classrooms from the schools. The NILM machines are accessed remotely via the Internet. Commercially available power metering and logging systems were also installed at the schools to provide parallel sub-metering of the monitored distribution panels in order to validate the observations made using the NILM machines.

The parallel power metering system used in the schools is a Highland Technology® sixteen-channel power meter and logger model K20. The K20 logger collects and stores one-minute averages of the power measured on each of the sixteen channels. The K20 data are retrieved using a serial connection to the NILM computer.

Daily power and energy consumption at the schools was measured using NILM machines instead of conventional metering equipment because of their applications besides metering. For example, a NILM machine is capable of identifying individual loads, or appliances, on the monitored circuit without additional monitoring equipment, providing not only information on the time of use of energy, but also identifying the loads consuming it. Data from the NILM can be used to track the energy consumption of individual loads, and to detect and diagnose equipment faults.

Hanna Ranch Elementary School

Hanna Ranch Elementary School is composed of five similar buildings housing classrooms and two larger buildings housing the staff and support offices, the library, the computer lab, a cafeteria, a performing arts facility, and a multi-purpose room. Each of the small buildings houses four classrooms and an interior small group teacher's room, with the exception of building E, which houses three classrooms, the electrical room, a storage room and student restrooms. Figure 20 shows a schematic plan of the school site.

The main panel NILM monitors the power consumed by the seven school buildings, while the secondary panel NILM monitors the power consumed only by building E. The K20 sub-metering system described previously was also installed at the secondary distribution panel.

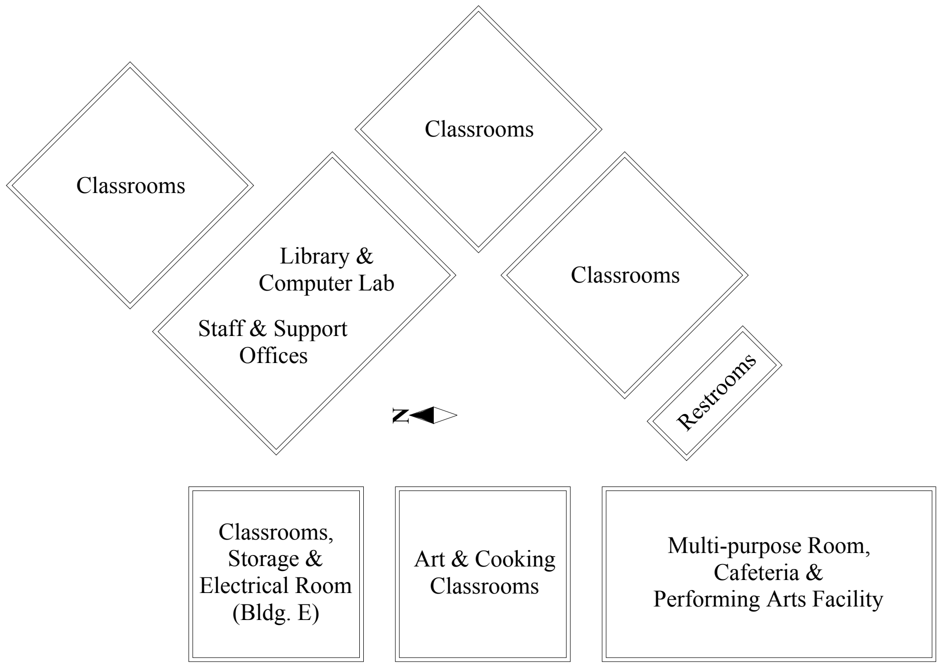

Figure 20 *Hanna Ranch School Schematic Plan.*

Main Distribution Panel

The following figures present samples of the power consumption recorded at the main electrical distribution panel of the school during the heating season. Each figure shows seven continuous days of power consumption. The first two figures (Figure 21 and Figure 22) show the power consumption during normal school weeks, while the third one (Figure 23) shows the power consumption during a school holiday week. Figure 24 shows samples of the three different diurnal cycles observed on the weekly plots. The following observations are made based on the mentioned figures.

- During school days, power consumption increases from the nighttime steady-state value at around 7:00 am reaching a plateau at 9:00. Power decreases around noon to increase again in the afternoon and decrease around 3:30 pm to an evening plateau at a higher value than the nighttime steady-state value. The evening plateau ends abruptly around 11:00 pm reducing the power consumption to the nighttime steady-state value.
- Weekend power consumption stays constant during the day at the nighttime steady-state value. At around 4:30 pm a step increase in power consumption is registered (the evening plateau) which ends around 11:00 pm to bring the power back to the nighttime steady-state value.
- Weekday power consumption during school holidays presents the same power consumption pulse observed from 4:30 pm to 11 pm during the weekend consumption. However, daytime consumption shows an increase in power use at 7 am that ends at 3:00 pm, although much smaller in magnitude than the increase presented during a normal school day. The smaller consumption is due to the fact that during the holiday only the administrative and maintenance staffs were present at the school.

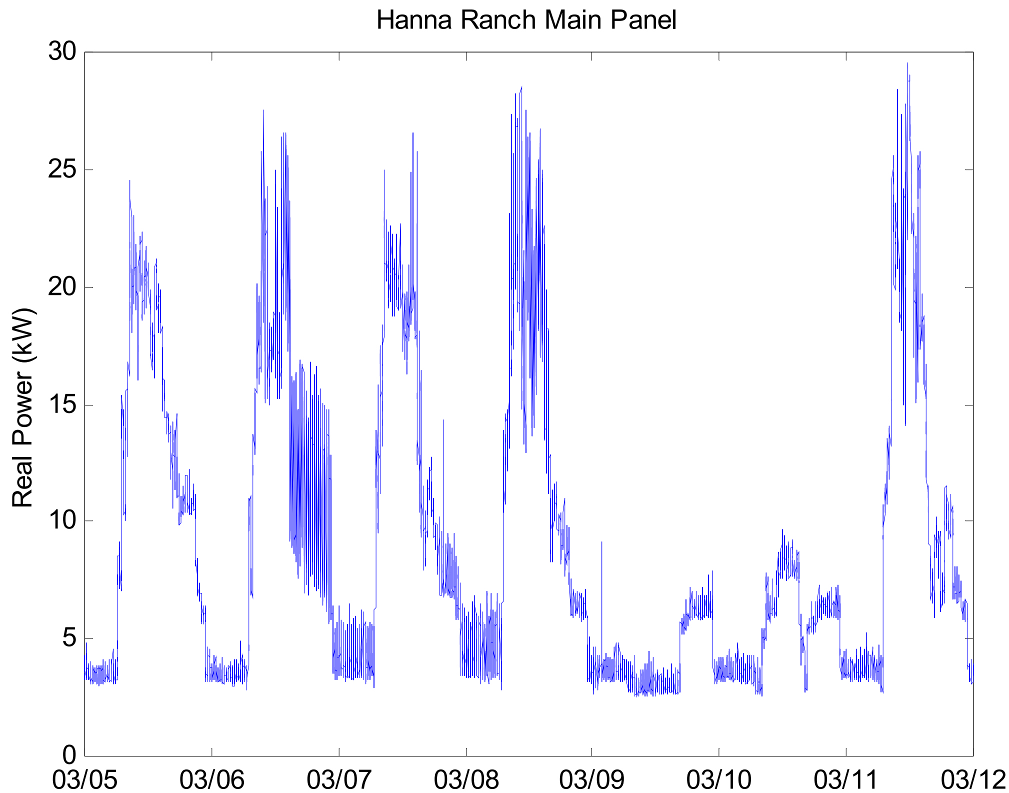

***Figure 21** Hanna Ranch Main Electrical Panel – Normal Week in March.2002*

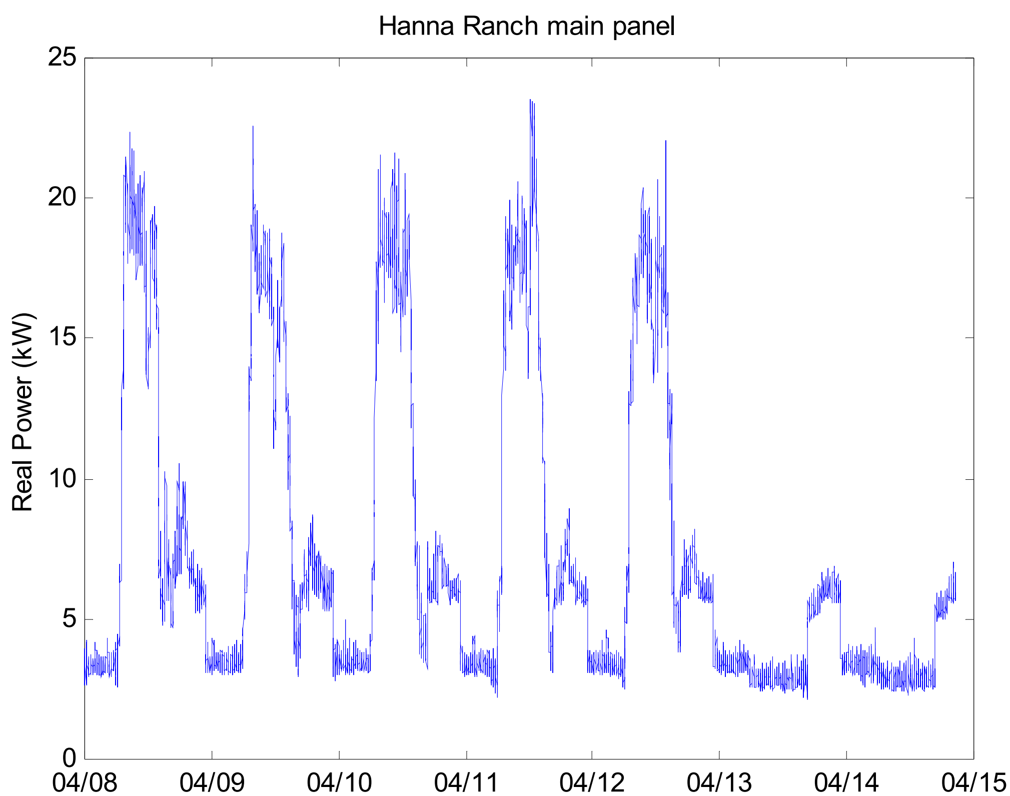

***Figure 22** Hanna Ranch Main Electrical Panel – Normal Week in April 2002*

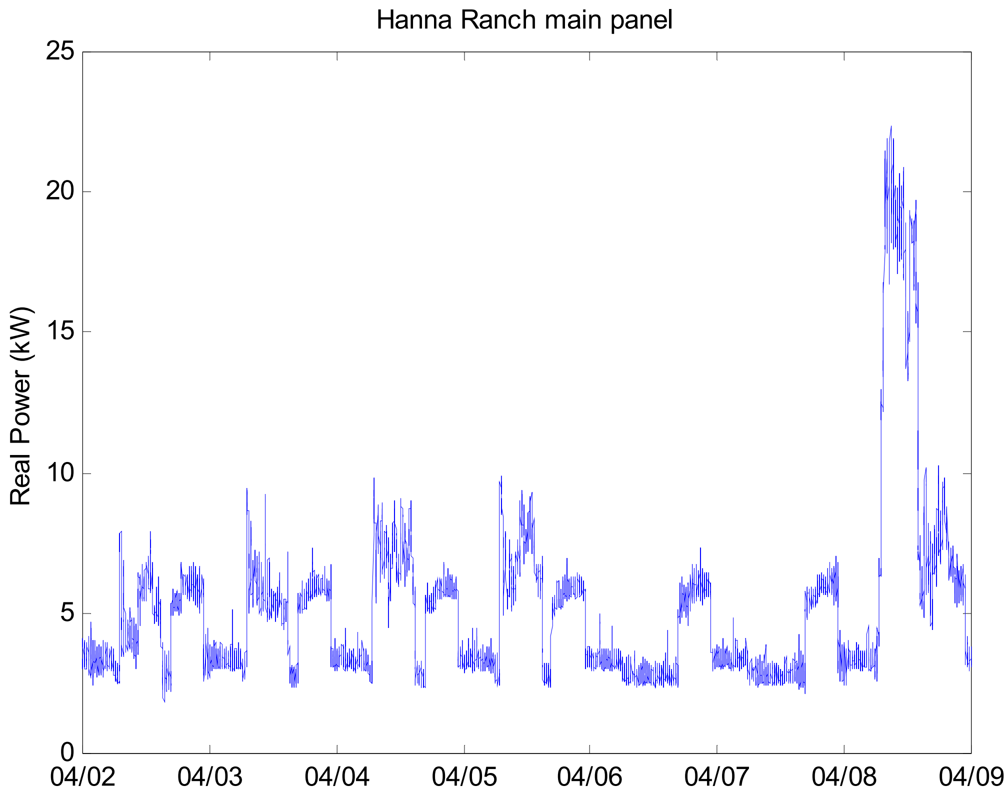

Figure 23 *Hanna Ranch Main Electrical Panel – Holiday Week, 2002.*

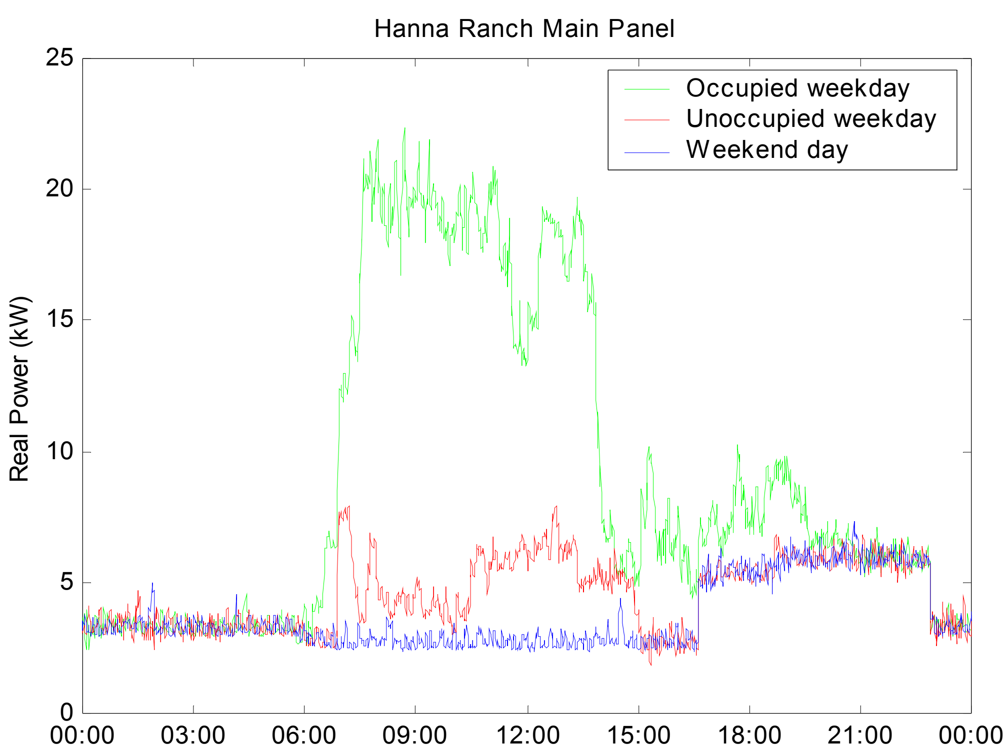

Figure 24 *The Different Daily Consumption Patterns at Hanna Ranch Main Panel.*

It is interesting to note in Figure 21 that some electrical activity was recorded during the afternoon of March 6, 2002, that was not observed during the other days presented. Figure 25 shows the power waveform recorded during March 6, 2002, and a detail of the observed oscillations.

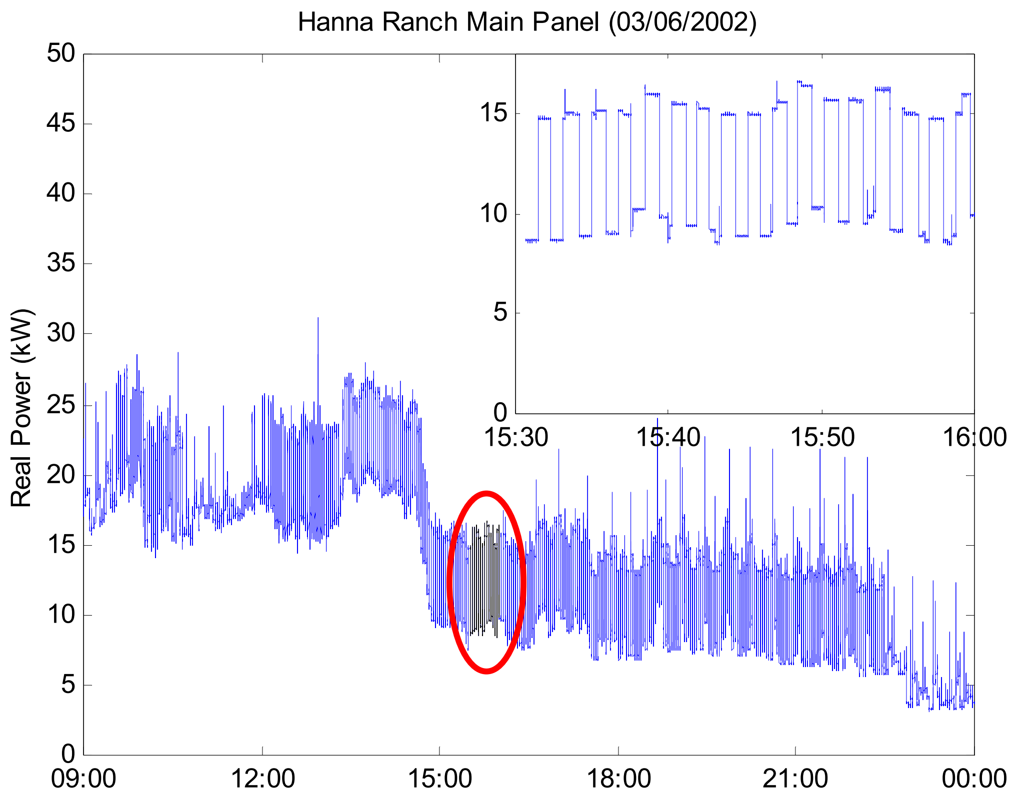

Figure 25 *Hanna Ranch Main Electrical Panel Consumption Detail on March 6, 2002.*

The shape and frequency of the oscillations observed suggests, based on previous experience, the operation of device containing a heating element or a motor, in either case controlled by a thermostat.

More detail on loads in Hanna Ranch is shown in Figure 26. The sharp spikes are typical of induction motor in-rush current, suggesting that the loads are one or more refrigeration units. The NILM at Hanna Ranch was not trained to track such loads, although the current version of the NILM software, prepared as part of a CEC PIER project but tested only at a single office building, is capable of doing so. However, the data show that the NILM is capable of resolving relatively small loads and can in concept be used to isolate refrigeration electricity usage and provide a basis for component-level benchmarking and tracking.

The oscillation shown in Figure 27 is much different than the one shown in Figure 26, mainly because of the higher frequency and shorter duration. In this case, the oscillation could be caused by the following:

- A device turning on and off extremely rapidly
- A device experiencing a regular periodic transient (e.g. electric motor speeding up and slowing down)
- Degraded current quality due to a faulty power supply within a device.

Regardless of the nature of the high frequency oscillation, it should not be viewed as trivial simply because the duration of the power spike is short. To use alternate language: *for the same magnitude of power, over a long period of time a spike of one second duration every minute will use as much power as a spike of one minute duration every hour!* Therefore, to limit the effect of this high-frequency oscillation on energy usage, the device should located and repaired if faulty or secured when not in use if functioning properly.

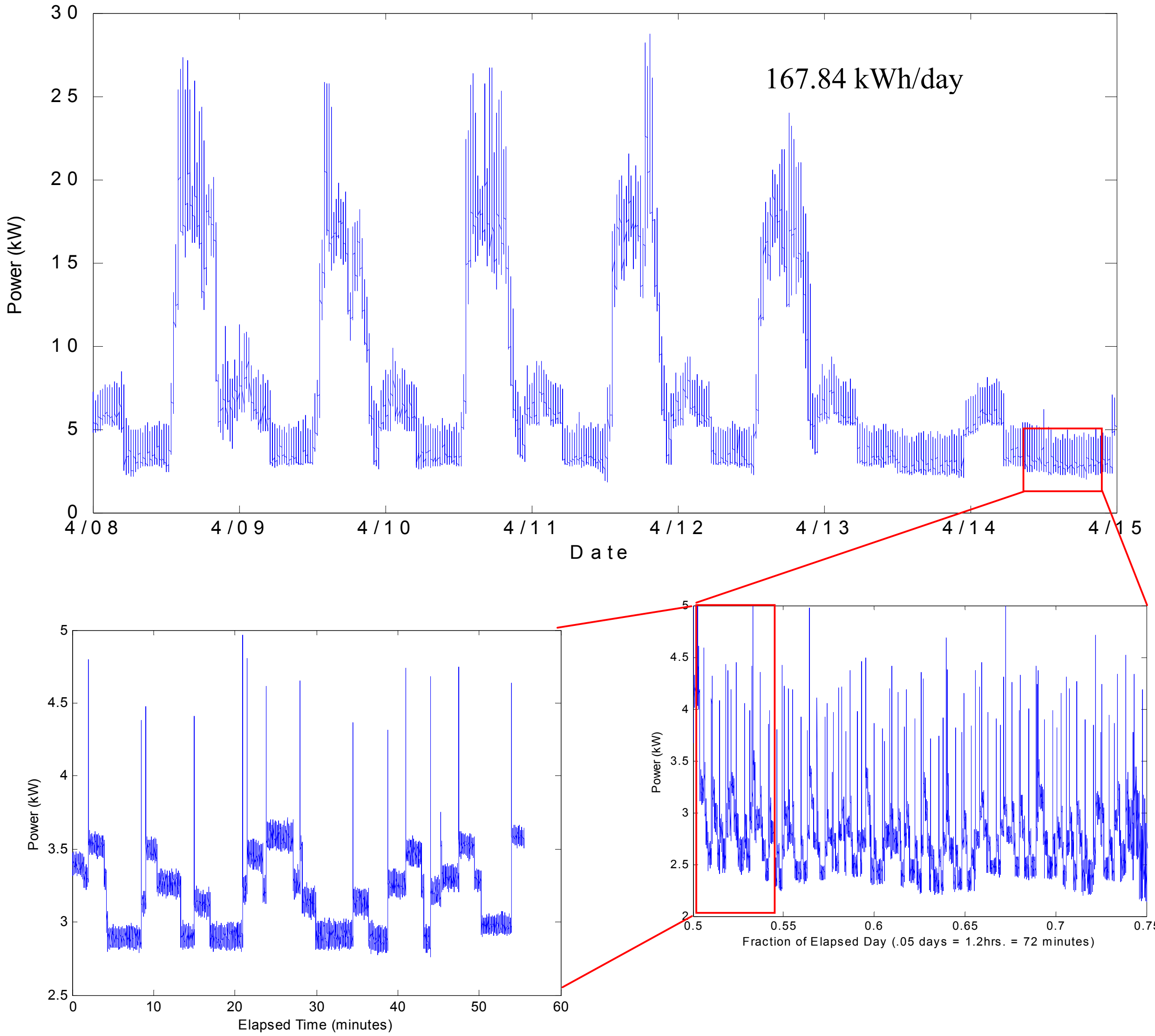

Figure 26 *Hanna Ranch Main Panel Consumption with Highlighted Detail, April 8-15, 2002*

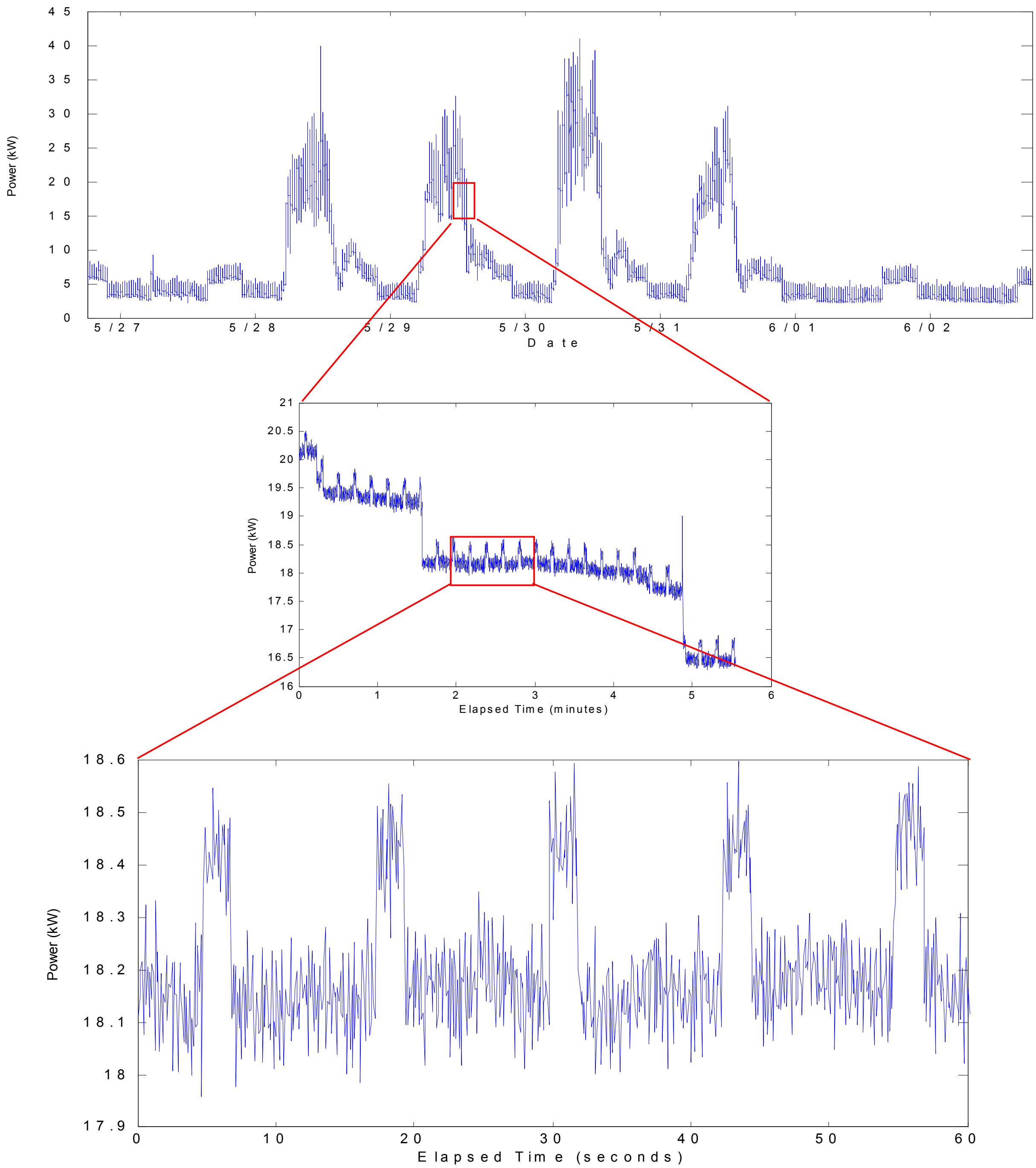

Figure 27 *Week at Hanna Ranch Elementary School with Highlighted Oscillations, May 27 – June 3, 2002*

Secondary Distribution Panel

As mentioned previously, the secondary electrical distribution panel being monitored at Hanna Ranch services a single building (building E) containing three classrooms, a small group room, a storage room, an electrical room, and student restrooms. Figure 28 presents a schematic plan view of building E showing the room distribution and orientation.

The HVAC (Heating, Ventilation and Air Conditioning) equipment in each classroom consists of a split air conditioning unit with gas fired heating, and an exhaust fan.

The evaporator/heater module of the air conditioning unit is installed inside the room, on the outside corner (opposite the small group room), while the condensing module is on the rooftop of the covered walkways. A duct with registers hanging from the ceiling is used for supply air. The classroom exhaust fan is located in the plenum space above the small group room. Exhaust air is removed from the room through registers on the wall and ducted to the outside. Fresh air intakes are located on each side of the outside corner of the room next to the windows, while exhaust air-louvers are located at the other end of the exterior walls. Return air to the evaporator-heater module is through grills next to the access door.

Figure 29 shows the layout of the HVAC equipment in the classroom as well as the air movement patterns. Pictures of the HVAC equipment are presented in Figure 30.

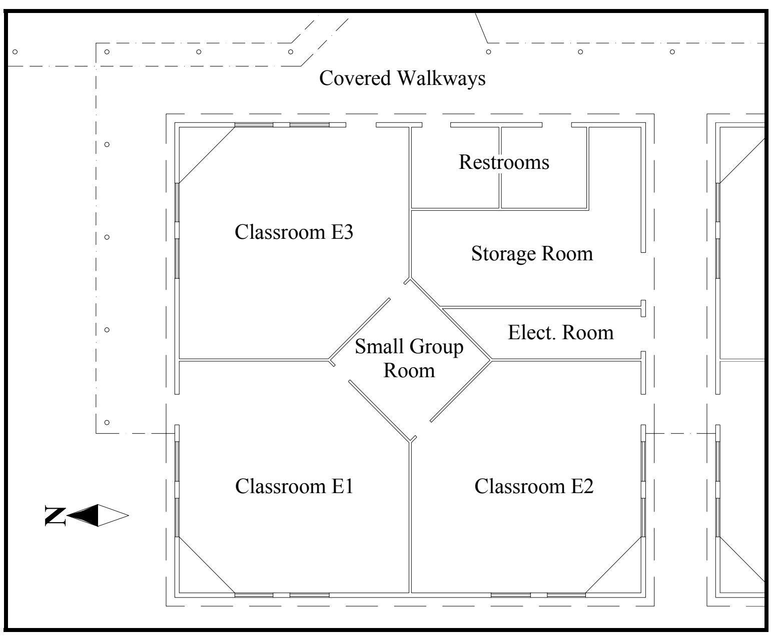

Figure 28 *Building E Schematic Plan and Classroom HVAC*

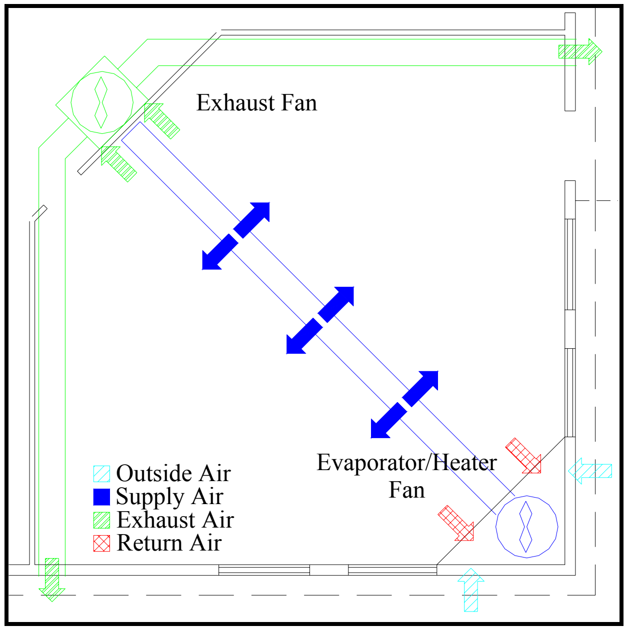

Figure 29 *Hanna Ranch Classroom HVAC Equipment Layout.*

Blue Supply Duct, Wall Exhaust Registers.

Green Exhuast Duct

Return Grill and Evaporator/Heater
Access Door

Fresh Air Intake (Left), Exhaust Louver
(Right), Roftop Condensing Unit

Figure 30 *Hanna Ranch Classroom HVAC Equipment Pictures.*

The classroom buildings construction is insulated stud walls with an air space and masonry veneer, insulated pyramidal galvanized metal roof, and concrete slab on grade. Physical data for the typical school classrooms are presented in Table 9.

Table 9 *Classroom Building Physical Data.*

Parameter	Value
Room Area	952 ft^2
Wall Height	11 ft
Wall Insulation	R19
Roof Insulation	R30
Fenestration Area per Wall	55 ft^2
Fenestration Insulation Value	0.6 Btuh/ft2-°F

An energy management system (EMS) is used at Hanna Ranch to control the operation of the mechanical equipment in the classrooms and offices. Table 10 presents the general settings of the EMS. Building users can override the EMS settings locally for a short period of time.

Table 10 *Energy Management System General Settings*

Name	Value
Occupied Start Time	7:30am
Occupied End Time	3:30pm
Cooling Set Point	74°F
Economizer Set Point	72°F
Heating Set Point	68°F
Dead Band	1.75°F

Lights in the classrooms are controlled manually, while a timer controls the night-lights outside the buildings. The timer turns on the lights at 4:30 pm (7:30 during the summer) and turns them off at 11:00 pm. Exhaust fans provide ventilation for the restrooms, the storage and electrical rooms. These exhaust fans are on non-switched circuits and they run continuously unless their breakers are turned off.

The loads monitored by the NILM and K20 systems are presented in Figure 31 and Table 11. The figure shows the load connections graphically, while the table describes the loads connected to each phase of the panel and the corresponding K20 channel used to monitor them. The K20 system is monitoring the loads connected to all three phases on the distribution panel. The NILM monitors only the loads on phase A.

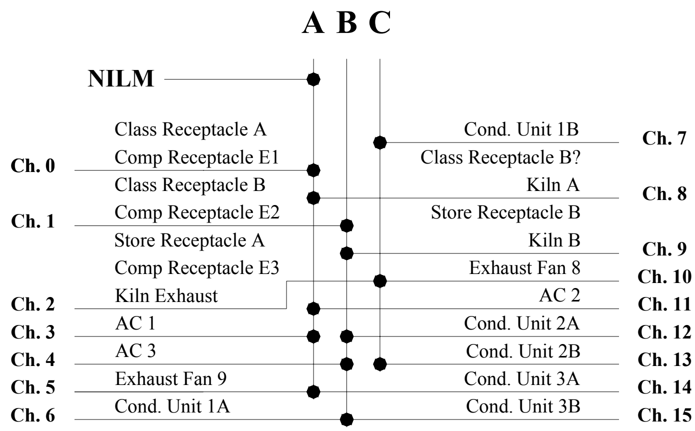

Figure 31 *Hanna Ranch NILM and K20 Sub-Panel Connections.*

Figure 32 and Figure 33 present the real power consumption recorded by the NILM on phase A of the sub-panel during two weeks. The first figure presents the power during a week in March (normal school week) when heating was used, and the second shows a week in June (summer vacation week) when the air conditioner was used.

Table 11 *K20 Monitored Loads by Circuit Phase.*

Phase	Channel No.	Load Descriptions
A	0	Classroom and Comp. Receptacles E1
	3	Split A/C Evaporator (heater) 1
	5	Exhaust Fan 9 (Electrical Room)
	8	Kiln A and Classroom Receptacles
	11	Split A/C Evaporator (heater) 2
	14	Split A/C Condensing Unit 3A
B	1	Classroom and Comp. Receptacles E2
	4	Split A/C Evaporator (heater) 3
	6	Split A/C Condensing Unit 1A
	9	Store Receptacles and Kiln B
	12	Split A/C Condensing Unit 2A
	15	Split A/C Condensing Unit 3B
C	2	Store and Comp. Receptacles E3, Kiln Fan
	7	Split A/C Condensing Unit 1B
	10	Exhaust Fan 8 (Restrooms)
	13	Split A/C Condensing Unit 2B

The figures show that there are devices on the monitored circuit that remained on continuously, and equipment on a periodic schedule (such as the night lights) turning on and off at approximately the same times every day. It can also be seen that some devices, such the HVAC equipment and classroom loads, operated during the daytime when the school was occupied (Figure 32: first five days; Figure 33: second and third days). In addition to the normal equipment, the June week waveform also shows that the kiln was used. These observations were verified using the data obtained from the parallel sub-metering system.

Figure 34 presents the K20 and NILM waveforms from March 18, 2002. Figure 35 presents the K20 and NILM waveforms from June 19, 2002. The following observations are based on the mentioned figures:

- The exhaust fan operates continuously during both the March and June days.
- Some loads on the receptacles and kiln circuits operate on a timer, while others are active during school days.
- The A/C evaporator/heater units operated during the March day only between approximately 7:00 am and 3:00 pm, the times the school is occupied. The A/C condensing unit did not operate because the system was in heating mode.
- The operation of the A/C evaporator units (Unit 1 and 2) observed by the NILM during the June day did not correspond to the observed condensing unit (Unit 3) because they are in different rooms, and therefore subject to different thermal loads.
- The kiln was observed only in the June, in both the NILM and K20 power waveforms.

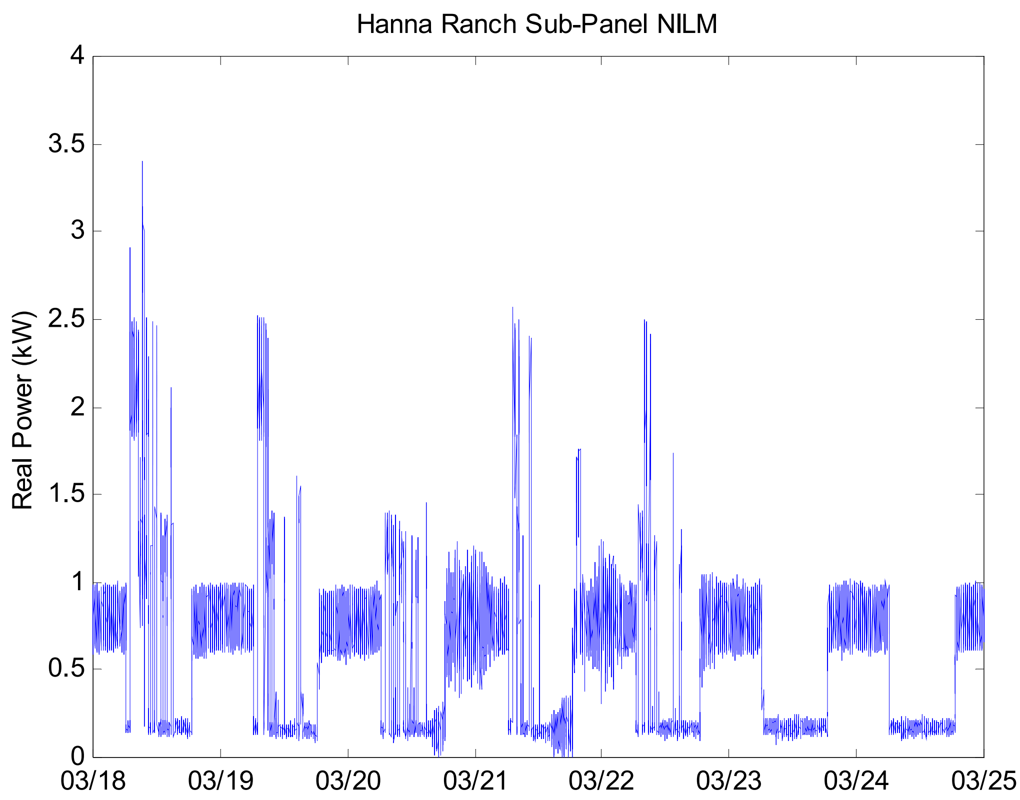

Figure 32 *Hanna Ranch Secondary Electrical Panel – Week in March 2002*

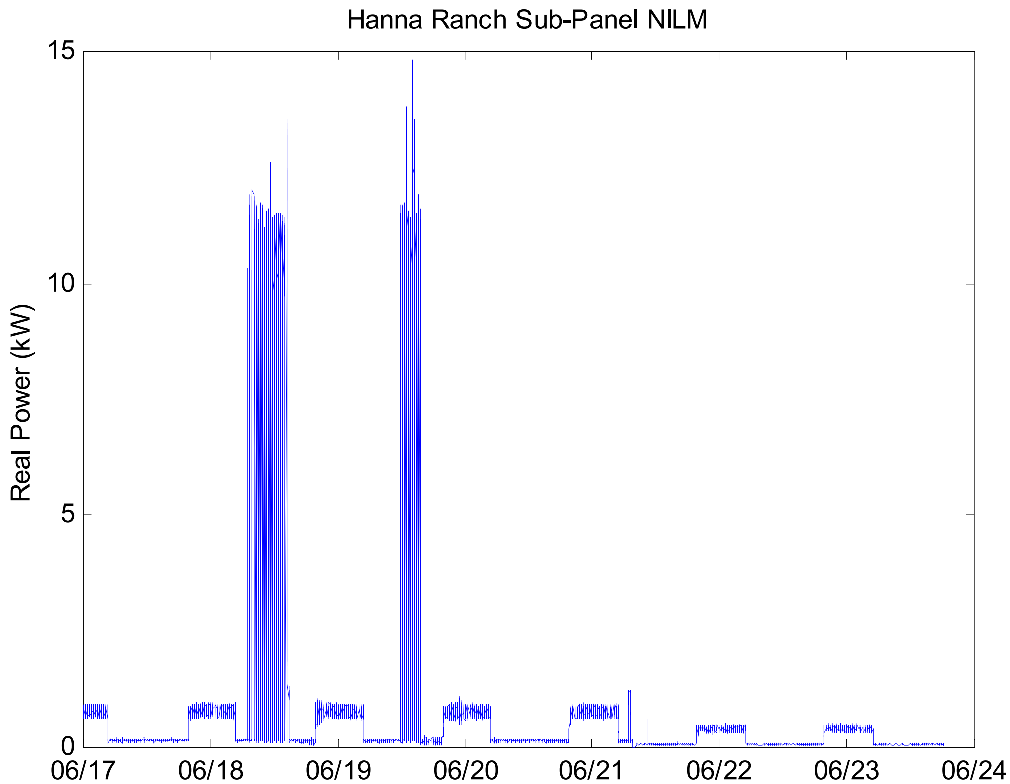

Figure 33 *Hanna Ranch Secondary Electrical Panel –Week in June 2002.*

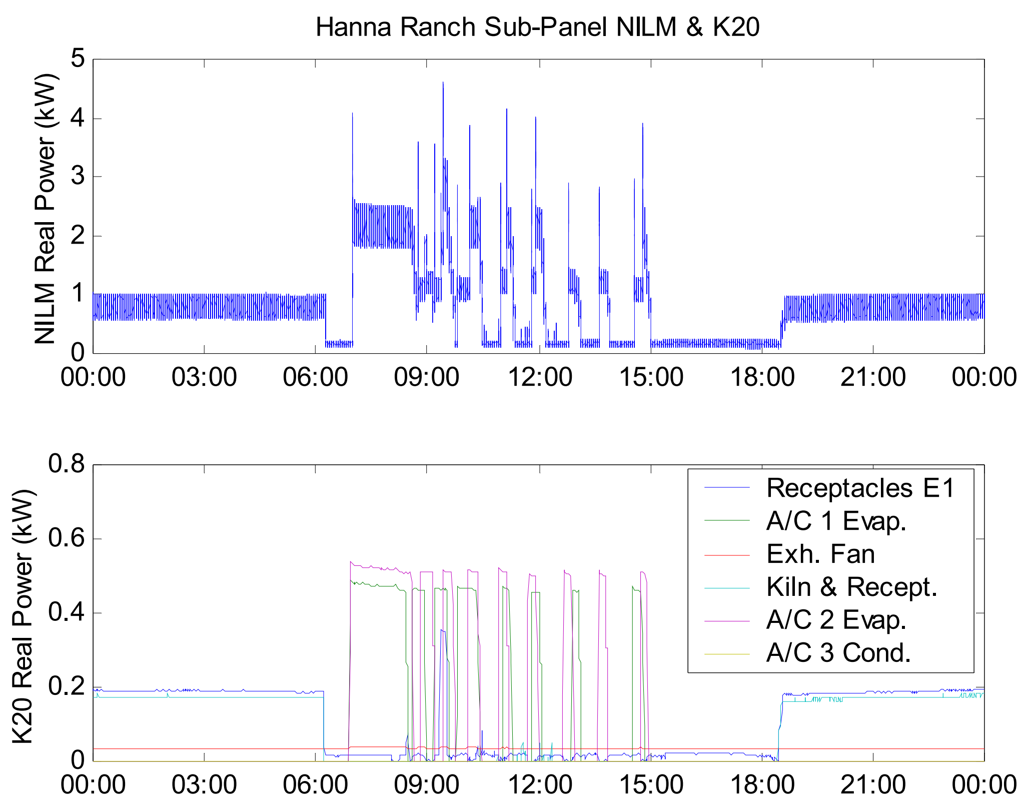

Figure 34 *Hanna Ranch Sub Panel NILM and K20 Waveforms. March 18, 2002.*

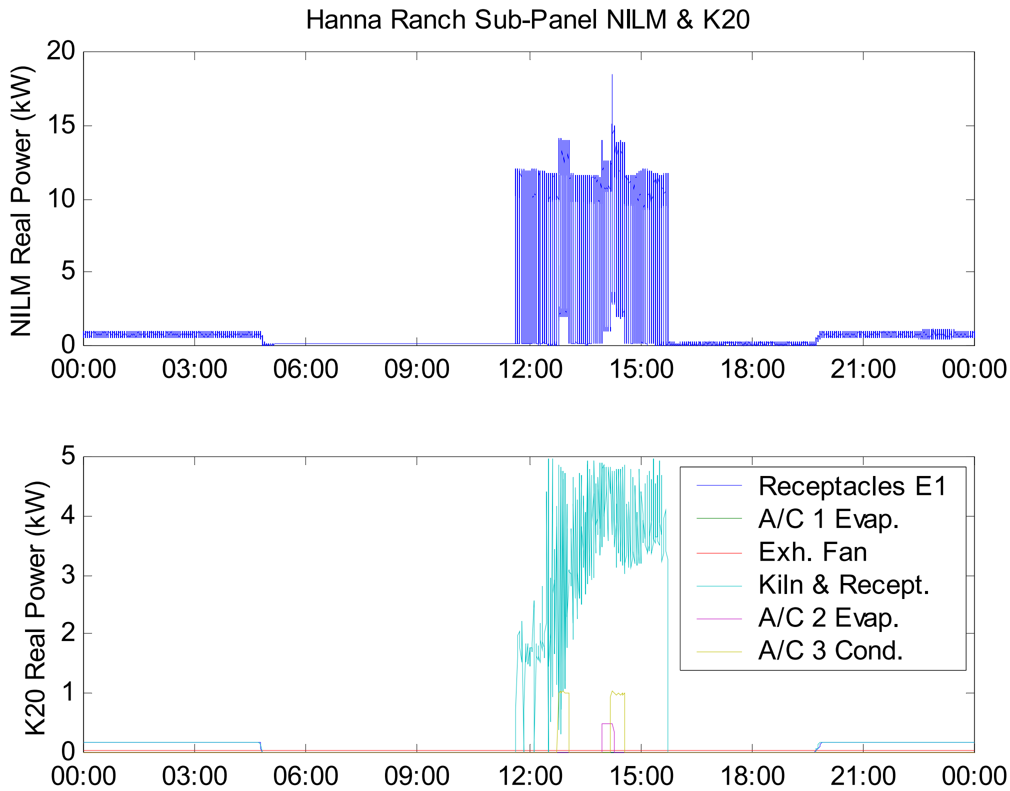

Figure 35 *Hanna Ranch Sub Panel NILM and K20 Waveforms. June 19, 2002.*

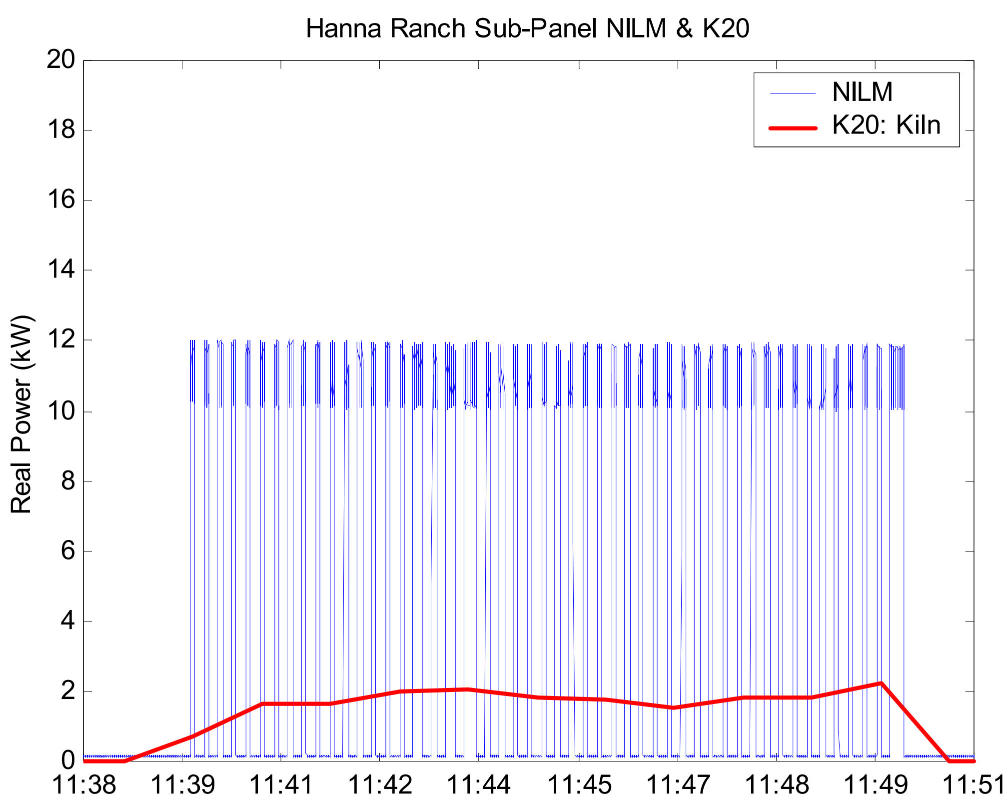

Figure 36 *Hanna Ranch Sub-Panel NILM and K20 Kiln Detail Power Waveform Comparison.*

Figure 36 shows a comparison between the NILM power waveform and the power consumption recorded by the K20 system on the kiln channel (channel 8) during a period the kiln operated. It can be seen that kiln oscillations are observable in the NILM waveform, while they are not in the K20 waveform. The observed kiln oscillations, although normal given the nature of the device, demonstrate one of the possible applications of the NILM currently under investigation: the detection, and possibly diagnosis, of faulty appliances on the monitored circuit. The oscillations could not be revealed by conventional metering or the sub-metering system, but were detected by the NILM system. The higher sampling frequency used by the NILM (1Hz versus 1/60Hz for the K20) produces the higher resolution of the NILM waveform.

Figure 37 shows a sample of the NILM waveform in June when the air-conditioning equipment operated, together with the waveforms corresponding to K20 channels monitoring the A/C. The NILM waveform presented also shows the kiln oscillations discussed previously, along with the events corresponding to the turn-on and shutdown of the evaporating and condensing units. The ability to distinguish and classify electrical events (turn-on and shutdowns) generated by different devices in the monitored circuit is one of the main features of the NILM system. It incorporates multiple metering points into a single metering point, reducing the complexity of the monitoring hardware and its installation.

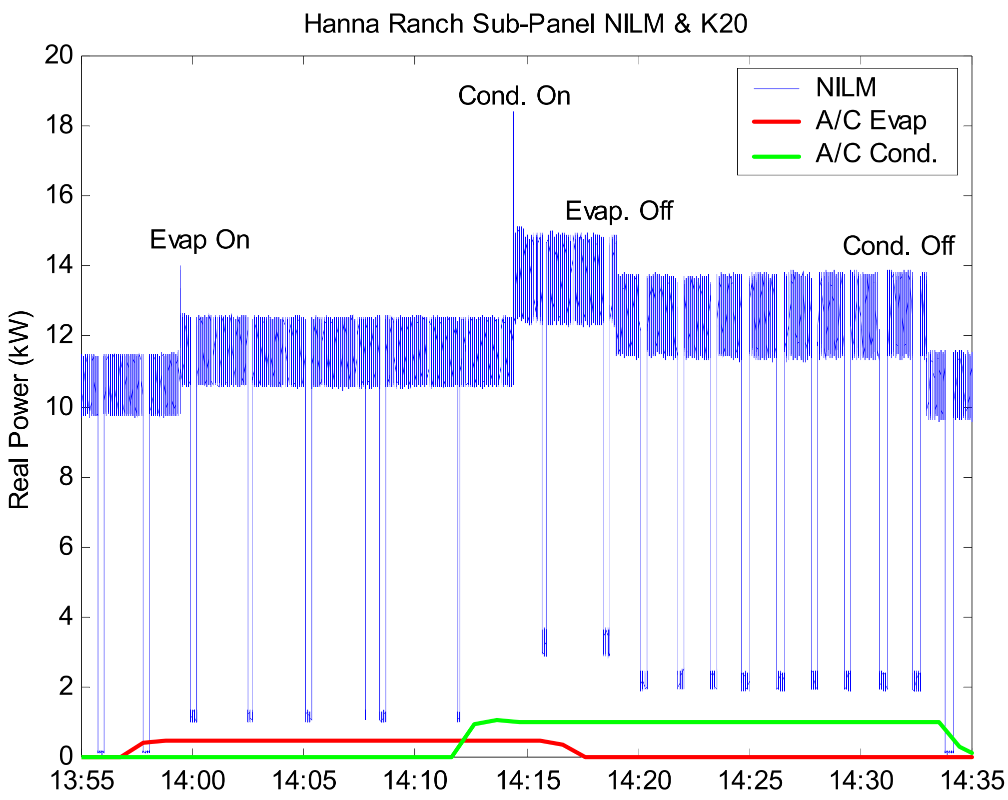

Figure 37 *NILM and K20 Waveforms Sample with A/C Components Operating.*

Pinole Middle School

The Pinole Middle School is composed of a main building (Figure 38), housing 22 classrooms, a multipurpose room, the cafeteria and the administrative offices. and a secondary building housing the library. Furthermore there are 26 portable classroom units on the site. The main building is heated using gas fired equipment and does not have air conditioning. The portable units are air-conditioned and heated using a heat pump unit for each classroom unit.

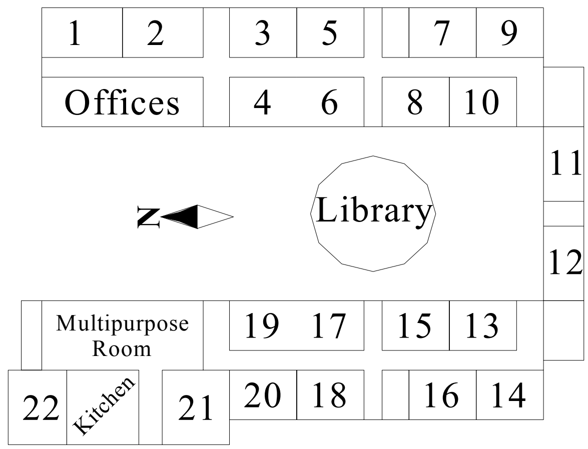

Figure 38 *Pinole Middle School Main Building Schematic Plan.*

Main Distribution Panel

The power consumption observed at the Pinole Middle School main electrical distribution panel is presented in Figure 39 through Figure 41. Again, seven continuous days are shown on each graph, with the last figure showing the power consumption during a holiday week.

The following observations about the Pinole Middle School power consumption are made based on the previous figures. Figure 42 summarizes these observations with sample power waveforms for each of the three daily consumption patterns observed.

- During school days the power consumption starts increasing from the nighttime steady state at about 6:00 am reaching a peak value between 9:00 and 10:00 am. Power consumption then decreases gradually and reaches the nighttime steady-state value at around 10:00 pm.
- Weekend power consumption stays constant at the night-time steady-state value, with a pulse increase in power showing up some Saturdays between 9:00 am and 6:00 pm.
- Weekday power consumption during school holiday presents the pulse shaped consumption that starts at around 8:00 am and ends around 3:00 pm. The magnitude of this pulse is slightly larger than the magnitude of the pulse present on Saturdays.

It is interesting to note that both in Hanna Ranch and Pinole, a non-zero steady state power consumption value was observed during all days. It could be attributed to loads continually on such as computer equipment, exhaust fans and kitchen equipment.

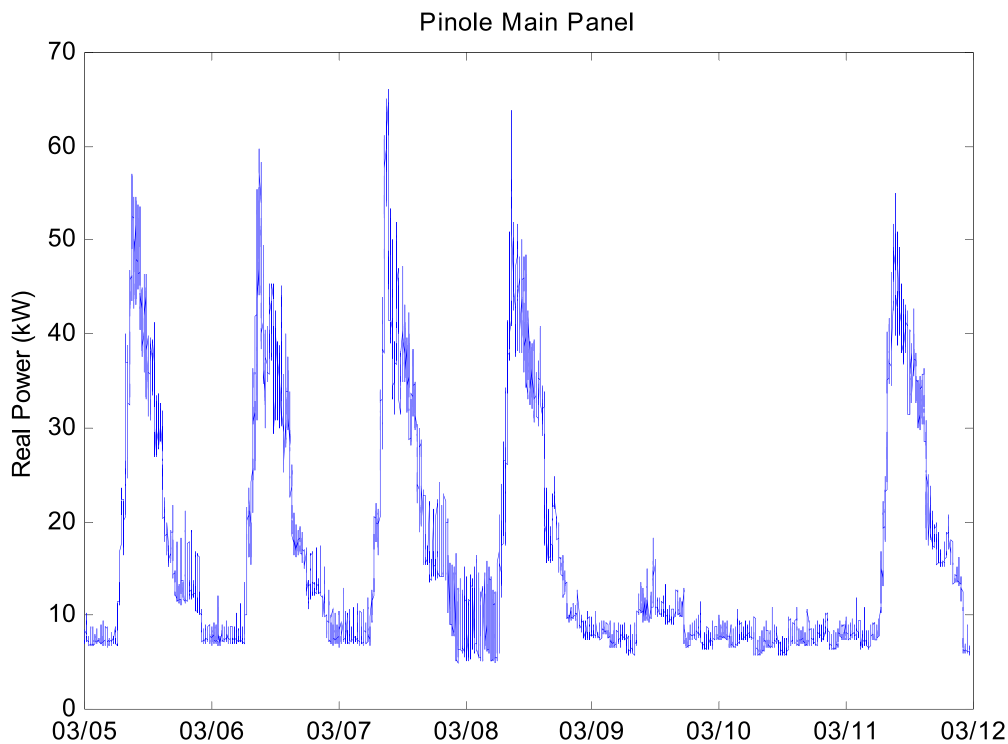

Figure 39 *Pinole Main Electrical Panel – Normal Week in March 2002*

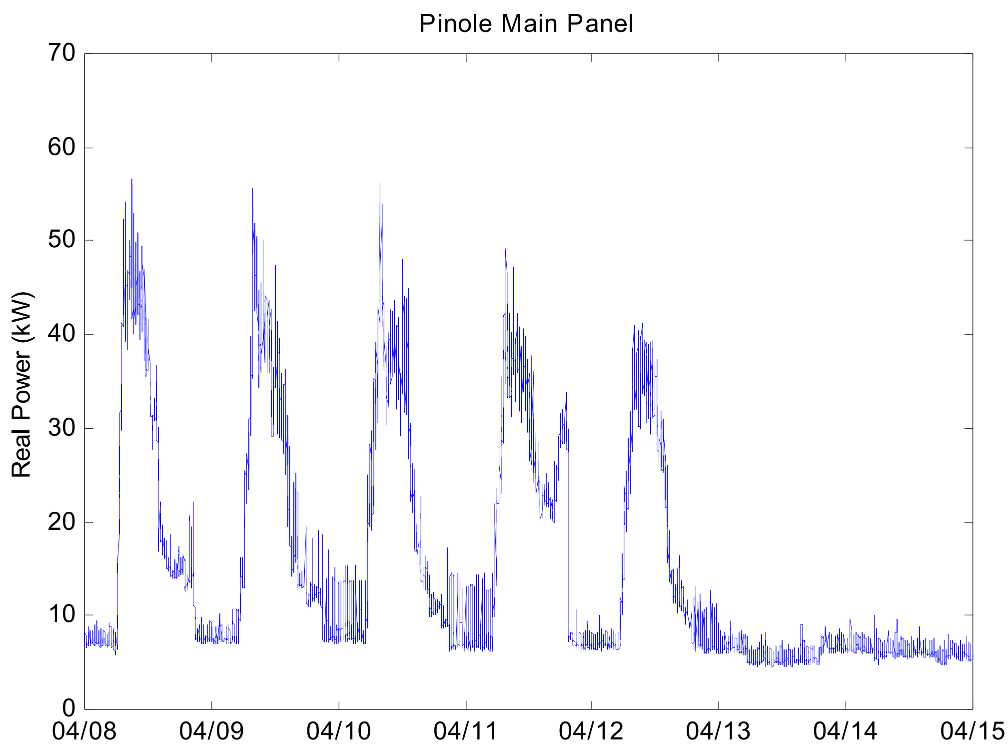

Figure 40 *Pinole Main Electrical Panel – Normal Week in April 2002*

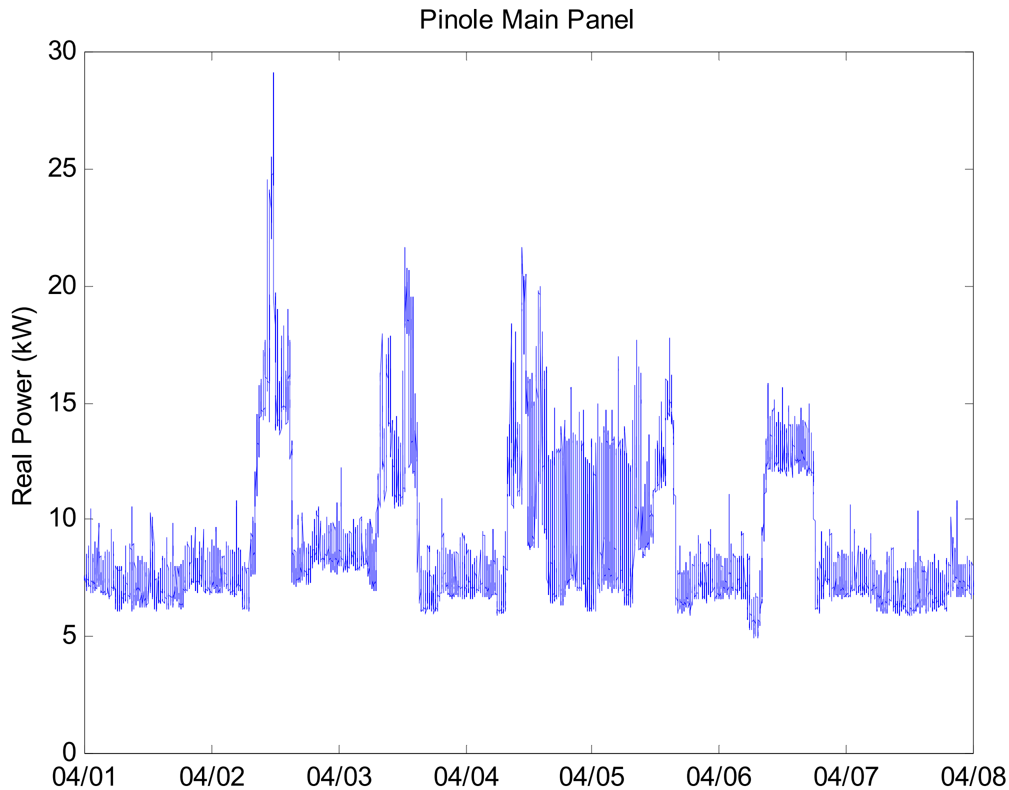

Figure 41 *Pinole Main Electrical Panel – Holiday Week 2002*

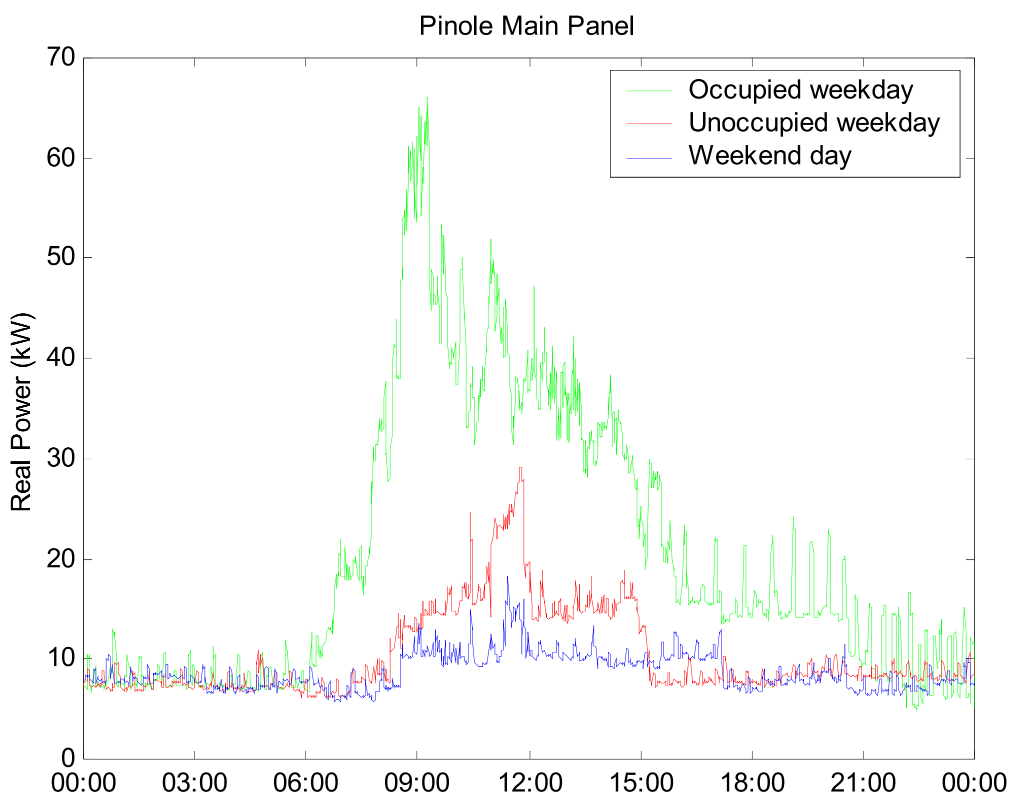

Figure 42 *Consumption Patterns for Different Day Types at Pinole Main Panel*

In addition to the consumption patterns described previously, the power waveforms of the March week (Figure 39) and the April holiday weeks (Figure 41) also show atypical power oscillations which could be indicative of potentially abnormal behavior of one or more devices. A sample of these oscillations, from the afternoon of March 4, is presented in Figure 43.

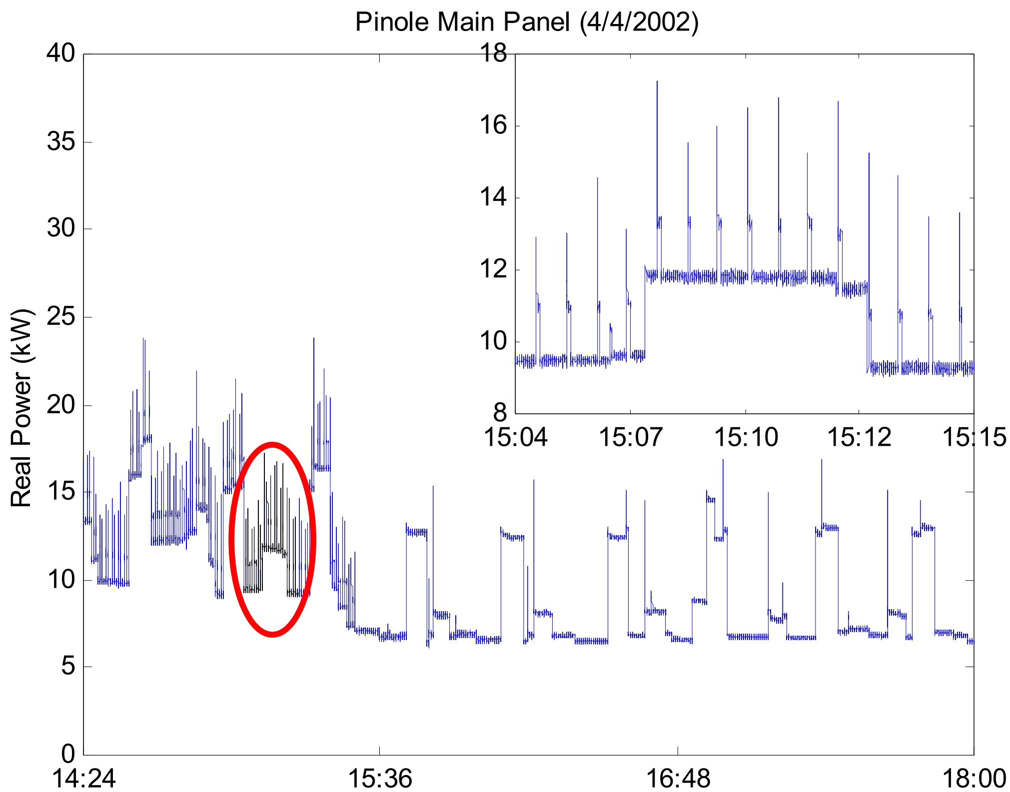

Figure 43 *Pinole Main Panel Consumption Detail on April 4, 2002.*

The detailed figure shows a device turning-on for approximately 6 seconds every 45 seconds. The shape of the device's turn-on transient (Figure 44) is similar to the one exhibited by inductive loads, such as motors.

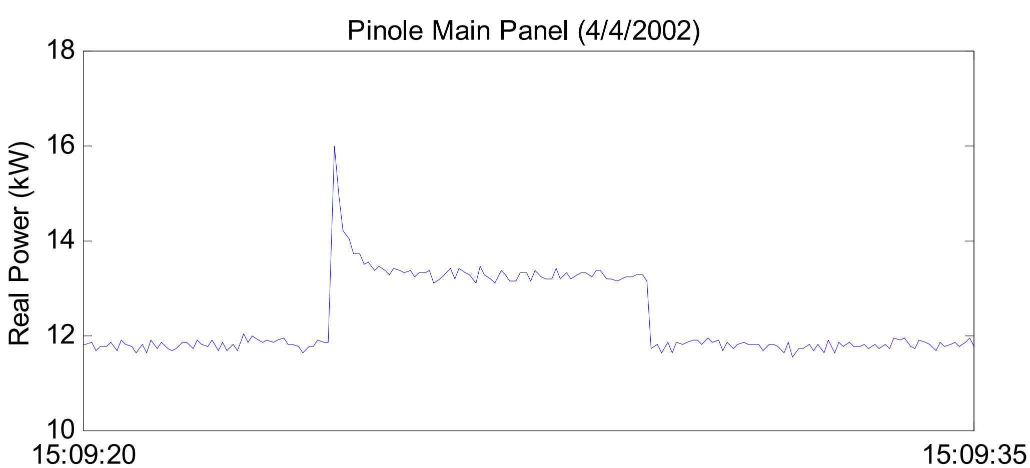

Figure 44 *Turn-on Transient for Oscillatory Device on Pinole Main Panel.*

Figure 45 shows a 1.5 kW spike that occurs every 25 minutes with duration of 5 minutes. Normally hidden by all of the occurrences during a normal school day, this regular power peak becomes clear on a Sunday afternoon. Although it could be a device on a timer, experience shows that steady oscillations of this magnitude, frequency, and duration are typically a thermostatically controlled device (e.g. hot water heater, refrigerator/freezer, etc.). The start-up spikes suggest, as for Hanna Ranch, that the load is a motor, likely a refrigeration compressor. It might be easy to dismiss such an oscillation, but multiple devices continually cycling on and off, even though of low power, can have a significant contribution to energy consumption when allowed to run for long periods of time. Were the load a hot-water heater, it should be possible to turn if off over unoccupied periods, with something as simple as a commercial off-the shelf timer.

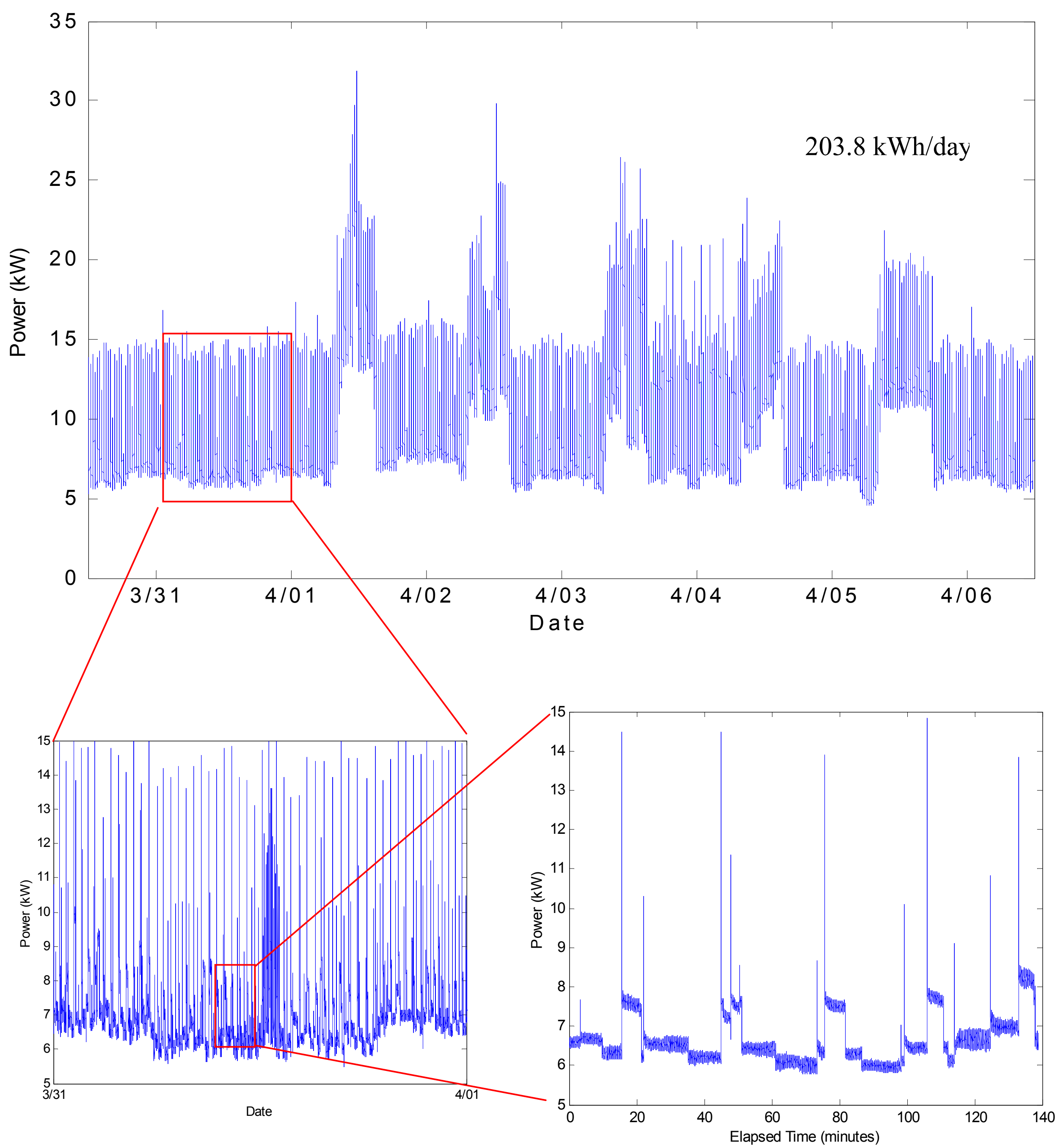

Figure 45 *Week at Pinole Middle School with Highlighted Oscillations, March 31 – April 6, 2002*

Figure 46 highlights another week for Pinole Middle School. The plateau shown in this figure occurs regularly at the end of each day (although partially obscured during normal school days) and represents a 1 to 1.5 kW increase in average power usage over a 4-hour period of time.

Both the raw data and a 15-minute average are plotted to provide a clear indication of the trends involved. Because the plateau occurs consistently at the end of each day, the following questions are reasonable:

- If due to night-lights, why have them on for only 4 hours at a time?
- Are the night-lights turning on at the correct time?
- If the night-lights were for security, would it make more sense to have them controlled by external or internal motion sensors?
- Are personnel leaving lights or other equipment (e.g. computers) on unnecessarily overnight?

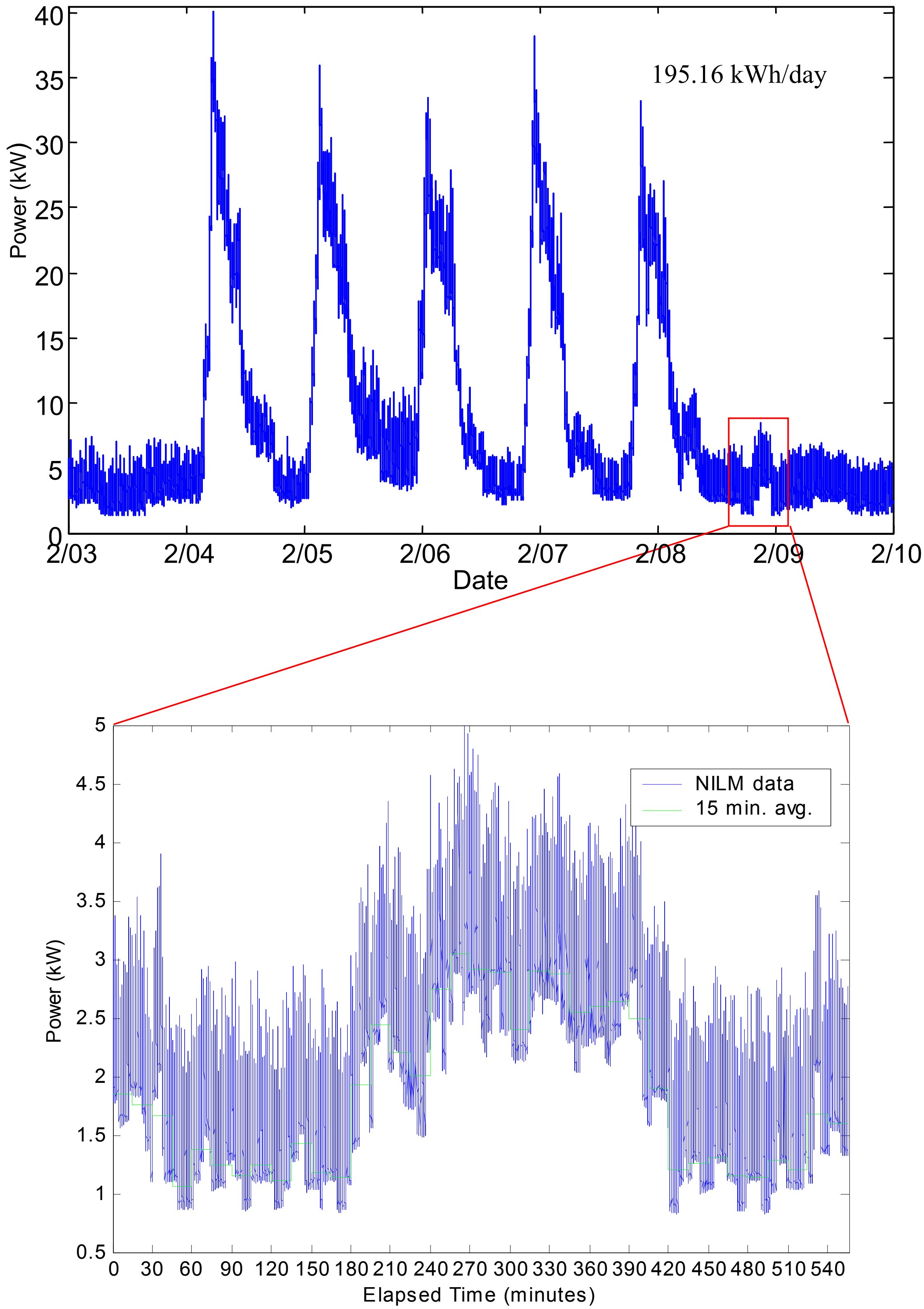

Figure 46 *Week at Pinole Middle School with Highlighted Power Plateau, February 3-9, 2002*

Secondary Distribution Panel

A NILM machine and a K20 parallel monitoring system were installed on the secondary electrical distribution panel of the Pinole Middle School that services the lights and receptacles of four classrooms. A sample of the real power recorded by the NILM on phase A of the sub-panel is presented in Figure 47 below.

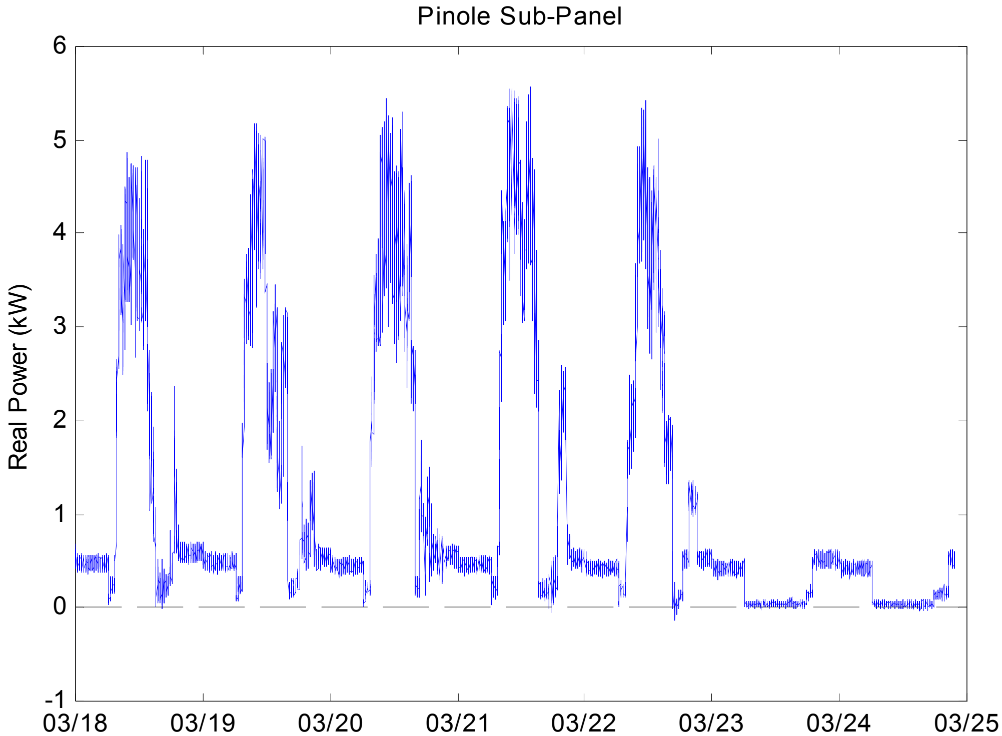

Figure 47 *Pinole Secondary Electrical Panel – Normal Week in March 2002*

The connections at the distribution panel as well as the loads monitored by both the NILM and the K20 systems are shown in Figure 48.

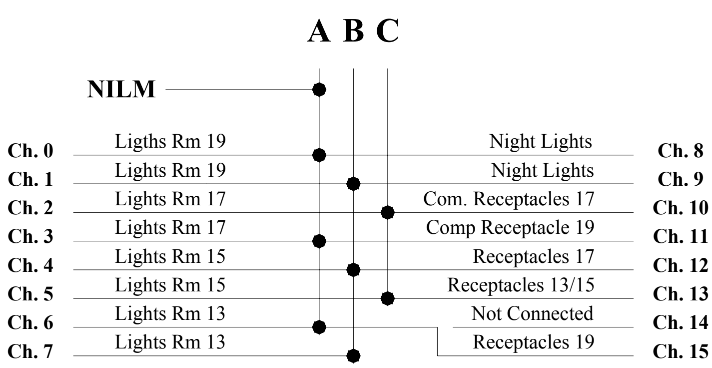

Figure 48 *Pinole NILM and K20 Sub-Panel Connections*

Rooms 17 and 19 are used as a computer laboratory. Room 15 is a normal classroom and room 13 is being used as a librarian office and book storage room. The computer laboratory classrooms are being used to demonstrate the energy consumption savings due to renovations made on those classrooms as part of a plan to reduce the energy consumed by the school. Rooms 13 and 15 are used as control rooms to compare the energy use of the new equipment used in the demonstration classrooms with the equipment prevailing in the school. Table 12 presents a comparison of the equipment used on each demo classroom and the equipment in the control classrooms. All the rooms monitored have the same dimensions (approx. 28'x30') with east facing windows.

***Table 12** Demo and Control Classrooms Equipment Comparison.*

	Demonstration	Control
Fluorescent Tubes (Quant.)	24	49
Type	T8	T12
Power (W)	32	40
Total Power (W)	768	1960
Lumens	2710	1800
Color Rendering Index	78	89
Color Temperature (K)	4100	4200
Incandescent Bulbs (Quant.)	None	3
Power (W)	-	100
Lighting Controls	Motion and Light Sensors	None
Computers	17	3

The following figures present samples of the power data collected by the different K20 channels on the Pinole Sub-Panel. Figure 49 presents two days (Friday and Saturday) of power data from the sub-panel loads other than the classroom lights. Figure 50 shows sample power consumption for the lights in the four classrooms serviced by the sub-panel during the same period of time. Each classroom waveform in the figure is the aggregate power read by two channels of the K20. Two channels per classroom were needed because the lights on each classroom are fed using two phases of the electrical panel. Figure 51 shows the power consumption when the lights are on.

The following observations are made from the mentioned figures:

- The classroom lights are turned on from before noon until around 10:30 pm, when the night-lights are turned on. The night-lights are turned off at about 5:30 am.
- As expected, the lights power consumption of the demonstration classrooms (17 and 19) is smaller than that of the control classrooms (13 and 15). However, the difference is not as big as predicted by the values in Table 12.
- The power consumed by the lights in room 19 is greater than that of room 17. The same power level was expected given that the same lighting equipment was used in both rooms. The lights consumption of room 17 agrees with the estimations in Table 12.
- The power consumption of the loads connected to the receptacles in rooms 17 and 19 is much greater than the loads in room 13 and 15. This is due to the use of rooms 17 and 19 as computer laboratory.

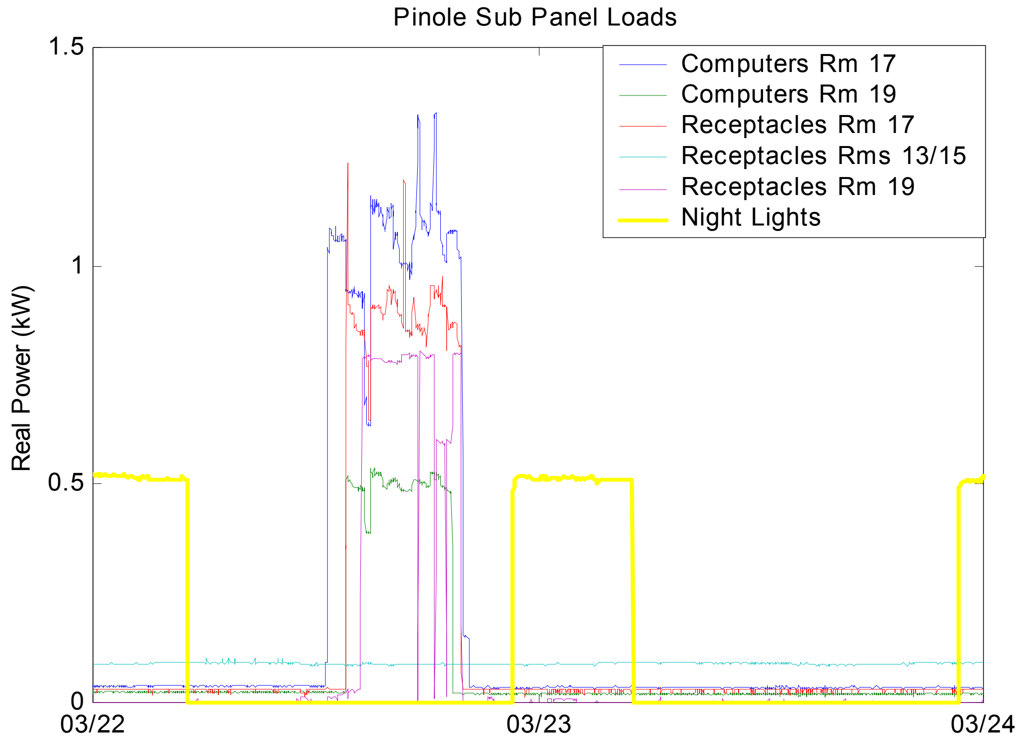

Figure 49 *Sample Power Consumption of the Sub-Panel Loads (Non-Classroom Lights)*

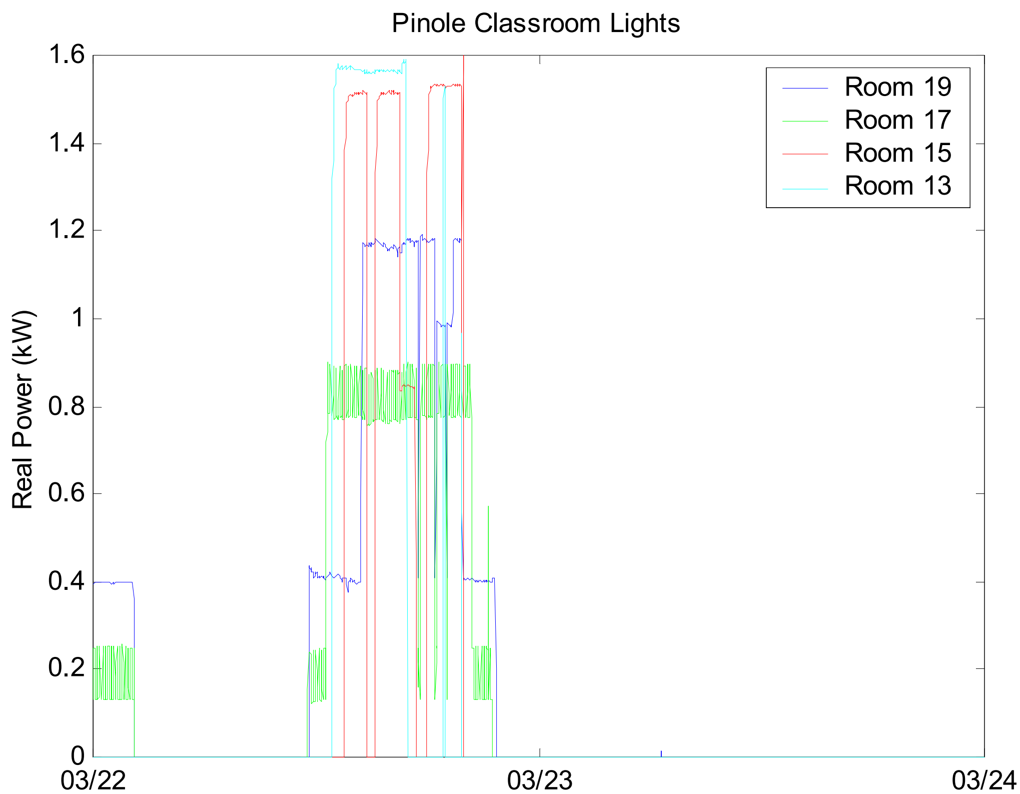

Figure 50 *Sample Power Consumption for the Classroom Lights (Demo Rooms: 13 & 15).*

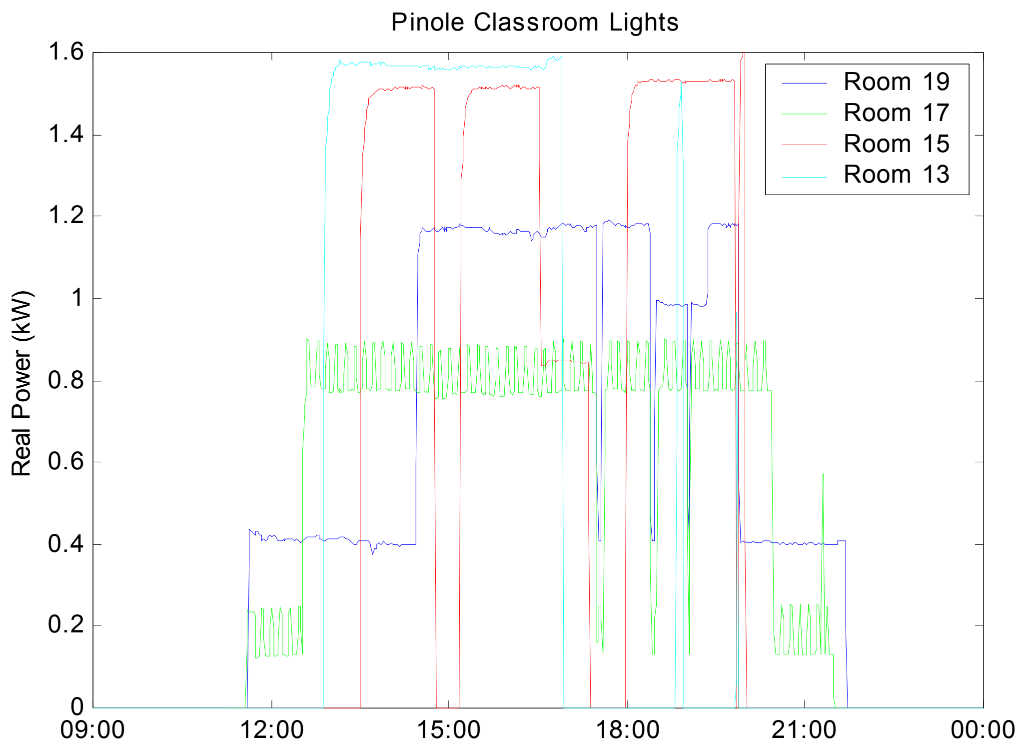

Figure 51 *Sample Power Consumption (Detail) of the Classroom Light.*

The energy consumed by the loads on the monitored sub-panel was estimated from the data collected by the K20 system. Table 13 presents a sample of the energy consumption of the classroom lights during four consecutive weeks, while Table 14 presents the consumption by the loads connected to the classroom receptacles.

Table 13 *Lights Energy (kWh) Consumption*

	3/18/2002	3/25/2002	4/1/2002	4/8/2002	Month Total
Total Lights Room 19	43.35	38.67	5.84	42.75	130.61
Total Lights Room 17	32.44	35.89	7.58	29.34	105.25
Total Lights Room 15	45.30	42.61	0.37	44.74	133.02
Total Lights Room 13	34.53	41.93	1.80	55.29	133.55
Total Night Lights	23.14	23.39	28.04	27.38	101.95

Table 14 *Sub-Panel Loads Energy (kWh) Consumption*

	3/18/2002	3/25/2002	4/1/2002	4/8/2002	Month Total
Computers Room 17	42.91	40.57	6.35	49.02	138.86
Computers Room 19	19.92	19.23	3.41	22.96	65.52
Receptacles Room 17	32.88	27.69	2.32	38.16	101.04
Receptacles Room 19	19.56	15.69	0.04	16.44	51.73
Receptacles Rooms 15/13	15.28	18.60	17.59	17.22	68.69

The lights in room 17 consumed the least amount of energy amongst the classrooms, even though they are on during the same times, normally (Figure 50), as lights in the other three classrooms. Lights in classrooms 13 and 15 consumed approximately the same amount of energy, while classroom 19 lights consumed slightly less energy than rooms 13 and 15.

The non-lighting loads in rooms 17 and 19 consumed more than twice the energy used by the loads in rooms 13 and 15. The computers and related devices in the demonstration classrooms are responsible of the higher non-lighting energy consumption in these rooms.

The high-energy consumption of lights in classroom 19, relative to classroom 17, suggests that the lights in the former room were on during longer periods of time during the month observed. Figure 52 shows the light power consumption patterns during the month studied. It can be seen that the lights in the demonstration classrooms were on during big part of the school holiday period, effectively offsetting the savings that could be attained by the more efficient lighting equipment. Those lights were the lights in room 19.

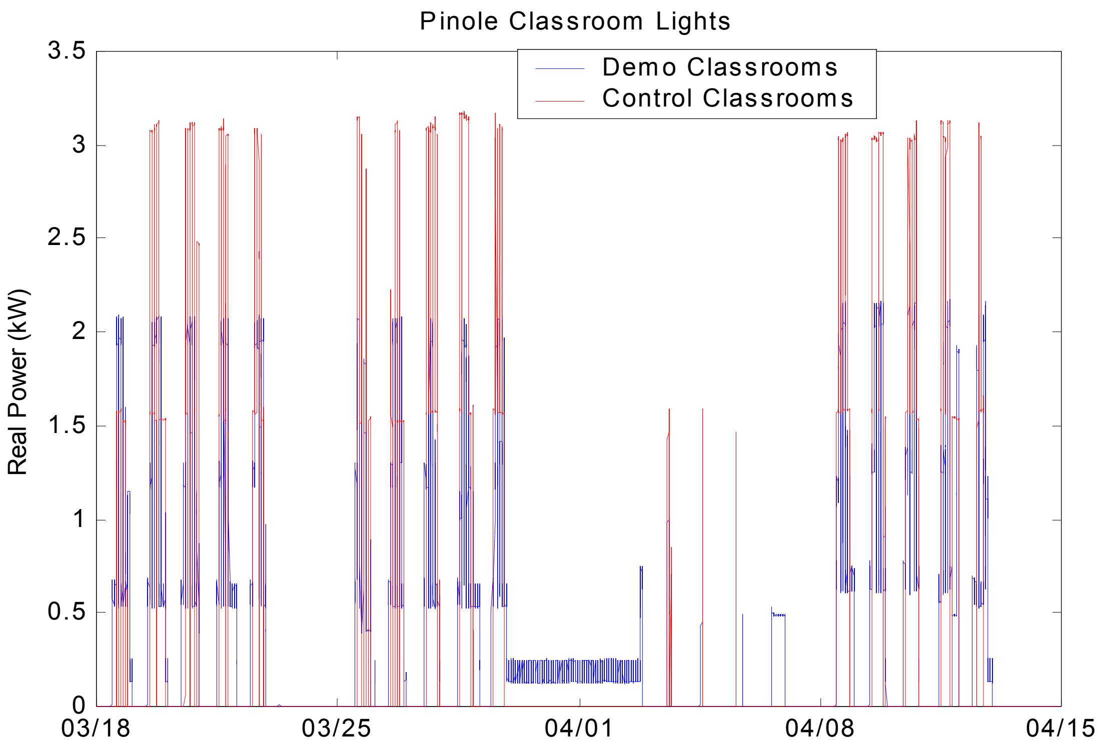

***Figure 52** Lighting Power Consumption during One Month*

For the four-week period, the energy consumed by the lights in room 17 was **21%** less than energy used by rooms 13 or 15. The energy consumed by room 19 was only **3%** less then that used by rooms 13 or 15. The combined savings of the lights in room 17 and 19 was of **11.5%** relative to energy used in rooms 13 and 15 combined. It is interesting to note that the lights in the demonstration classrooms remained on during longer periods of times than in the control classrooms, therefore reducing the energy saved.

NILM Energy Information Feedback

The Non-Intrusive Load Monitoring system can provide building operators and owners with detailed information on the building's electrical equipment operation in addition to the data provided by conventional power metering systems.

The energy consumed by different devices on a circuit can be tracked using a NILM system, providing detailed time-of-use information. Knowing where and when energy is used helps identify possible energy and cost saving measures. For example, loads which stay on longer than required can be identified, as well as loads operating during peak-times.

The NILM system is also capable of revealing equipment behavior, such as oscillations, that cannot be observed using conventional (low frequency) metering systems. Based on these observations, equipment control strategies can be tuned, for example to reduce cycling and therefore wear and maintenance costs. Abnormal equipment behavior and power consumption, indicative of possible faults, can also be detected and identified using the NILM power data.

Work in the third year of the project will, in part, focus on making NILM information available to WCCUSD staff and assessing their use of this information. To this end, NILM output was shared with school officials and others during a series of meetings, later in this report.

Assessment of Night Cooling in Hanna Ranch

The evaporator/heater module of the air conditioning unit is installed inside the room, on the outside corner (opposite the small group room), while the condensing module is on the rooftop of the covered walkways. Supply air is introduced in the classroom through registers on a duct hanging from the ceiling. Exhaust air is removed from the room through registers on the wall and on the duct hanging from the ceiling. A bulkhead is used in the ceiling duct separate supply and exhaust air. The classroom exhaust fan is located in the plenum space above the small group room and exhausts air to louvers located on the exterior walls. Fresh air intakes are located on each side of the outside corner of the room next to the windows. Return air to the evaporator-heater module is through grills below the module access door. The specifications for the HVAC equipment are presented in **Table 15**.

Table 15 *HVAC Equipment Specifications.*

Exhaust Fan	Evaporator/Heater	Condensing Unit
Voltage: 480V, 3ø Power: 1 ½ hp Volume flow rate: 5200 cfm Static pressure: ¾"	Voltage: 120V, 1ø Power: ½ hp Volume flow rate: 1200 cfm, 10% OA Static pressure: ½" Heating capacity: 40 kBtuh	Voltage: 208V, 1ø Cooling capacity: 37 kBtuh

An energy management system (EMS) is used at Hanna Ranch to control the operation of the mechanical equipment in the classrooms and offices. Table 16 presents the general settings of the EMS. Building users can override the EMS settings locally for a short period of time.

Table 16 *Energy Management System General Settings.*

Name	Value
Occupied Start Time	7:30am
Occupied End Time	3:30pm
Cooling Set Point	74°F
Economizer Set Point	72°F
Heating Set Point	68°F
Dead Band	1.75°F

Experiment Setup Description

The nighttime cooling experiments were performed on classroom E2 (Figure 28). Classrooms E3 and E4 were used as control classrooms. Classroom E4 outside walls face north and east, and they are shaded by the school's main corridor roof. Classroom E3 has non-shaded outside walls, one facing west and the other facing north. Classroom E2 has a west non-shaded outside wall, and a partially shaded south-facing wall. Internal heat gains for the three classrooms are similar.

Mr. Richard Jackson from the WCCUSD Maintenance Department was asked to manually override the EMS program in order to run the classroom fans at night according to the schedule presented in **Table 17**. To simplify the programming of the fans operation, we asked that they were set to run continuously from 11pm to 5am every night on the weeks the experiments were to be conducted. No intent was made to modify the fan control algorithms due to the nighttime cooling. The fans operated independently of the room or outside air temperatures.

Table 17 *Classroom E2 Nighttime Fan Operation Schedule.*

Dates	Fan
7/1/02-7/7/02	Exhaust
8/5/02-8/11/02	Exhaust
8/12/02-8/18/02	Evaporator
9/2/02-9/8/02	Exhaust
9/9/02-9/15/02	Evaporator
9/16/02-9/22/02	Evaporator
9/23/02-9/29/02	Exhaust

The energy consumption for the three classrooms air conditioning units was continuously recorded by the K20 monitoring system while the experiments were conducted, and also while they were not conducted. The energy consumed by the exhaust fan was not monitored because it is connected to a 480V panel, which feeds the monitored panel through a step-down transformer.

Temperature measurements, classroom and outdoor temperatures, were taken using Onset Corporation Hobo® Temperature loggers. However, site temperature information from the test weeks were lost due to difficulties encountered while retrieving the data.

Experimental Results and Discussion

Table 18 presents the energy consumed, in kWh, by the air-conditioning units in the three monitored classrooms. Night cooling tests were only conducted using the exhaust fan since it was not possible to run the evaporator fan independently of the compressor.

Table 18 *Building E Weekly Air Conditioning Energy Use during Test Weeks (in kWh).*

Week	A/C 1 (Room E4)		A/C 2 (Room E3)		A/C 3 (Room E2)		
	Evaporator	Compressor	Evaporator	Compressor	Evaporator	Compressor	Fan
6/24/02	2.50	0.60	2.78	1.54	2.54	1.55	None
7/1/02	2.16	1.81	2.06	1.70	0.95	0	Exhaust
8/5/02	1.96	0.032	2.86	2.20	2.67	3.34	Exhaust
8/12/02	0	0	0.48	0.86	0.95	1.91	None
9/2/02	1.98	3.68	2.84	4.94	3.66	7.40	Exhaust
9/9/02	1.03	1.78	2.44	4.30	4.18	8.78	Exhaust
9/16/02	2.48	5.06	4.31	7.84	6.39	13.92	Exhaust
9/23/02	1.20	2.42	1.97	3.44	4.13	8.80	Exhaust

Figure 53 shows the total weekly energy consumed by the A/C equipment in each classroom from the week of June 24, 2002 to the week of September 23, 2002.

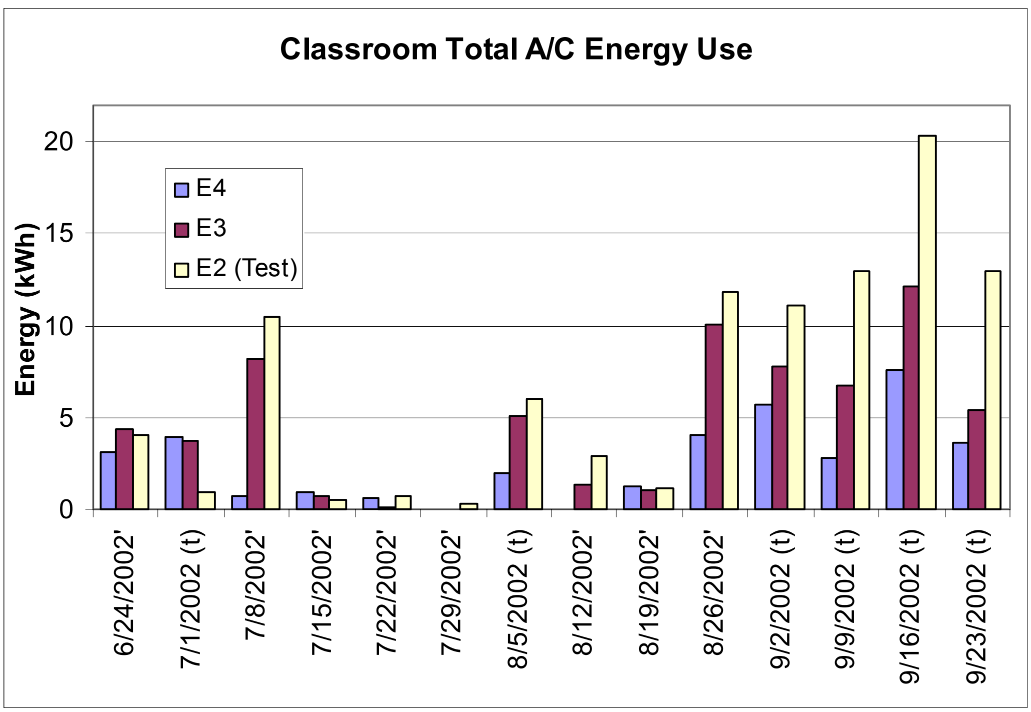

Figure 53 *Classroom A/C Total Weekly Energy Consumption*

Figure 54 shows the hours heating was used each week in each classroom, while **Figure 55** presents the hours cooling was used. Together with **Figure 53**, it can be seen that when cooling was used, the test classroom (E2) used more energy than the control classrooms. During heating, classrooms E2 and E3 consumed similar amounts, while classroom E4 consumed more energy.

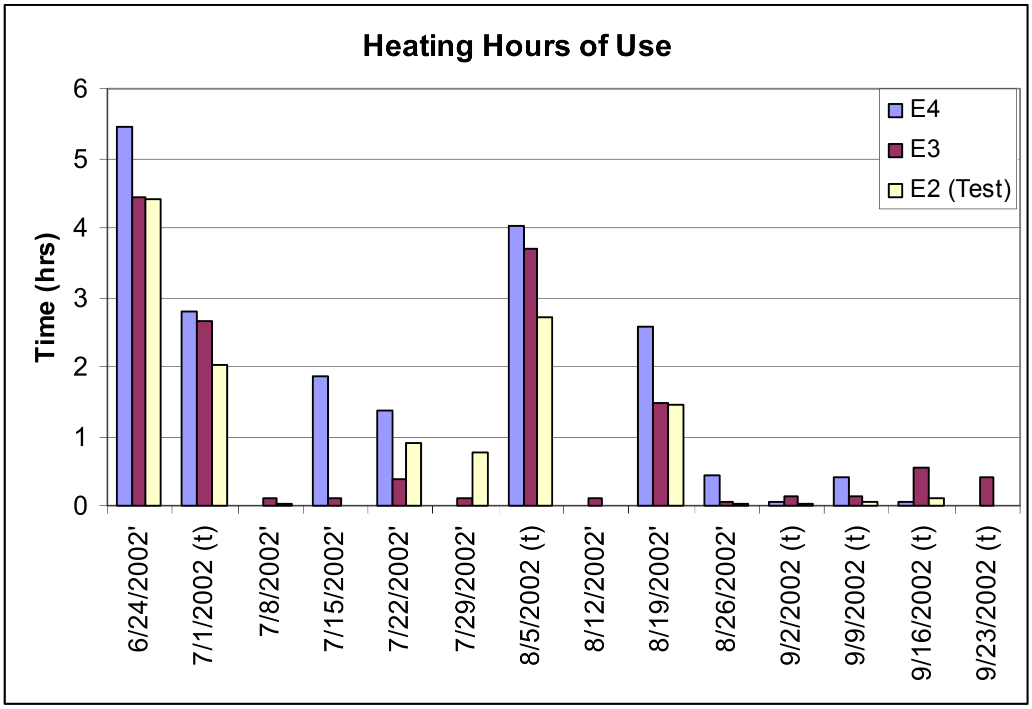

Figure 54 *Weekly Heating Hours*

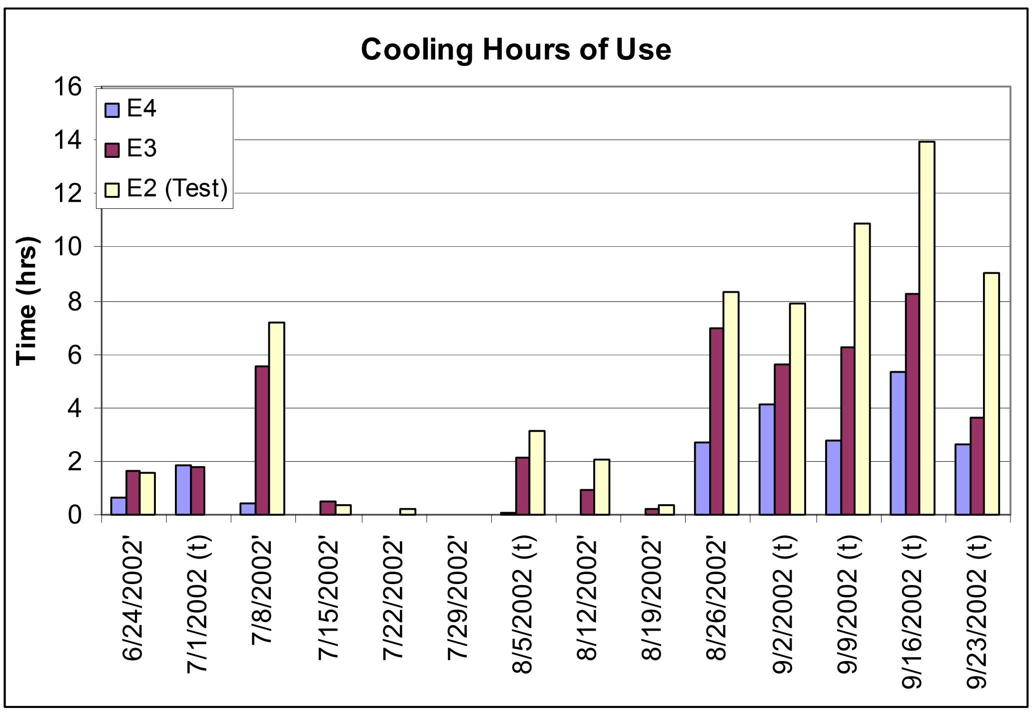

Figure 55 *Weekly Cooling Hours*

The electrical energy consumed by the evaporator/heater and the compressor modules in each classroom are presented in **Figure 56** and **Figure 57**, respectively. The evaporator/heater module uses electrical energy during both cooling and heating cycles, while the compressor unit only uses energy during the cooling process.

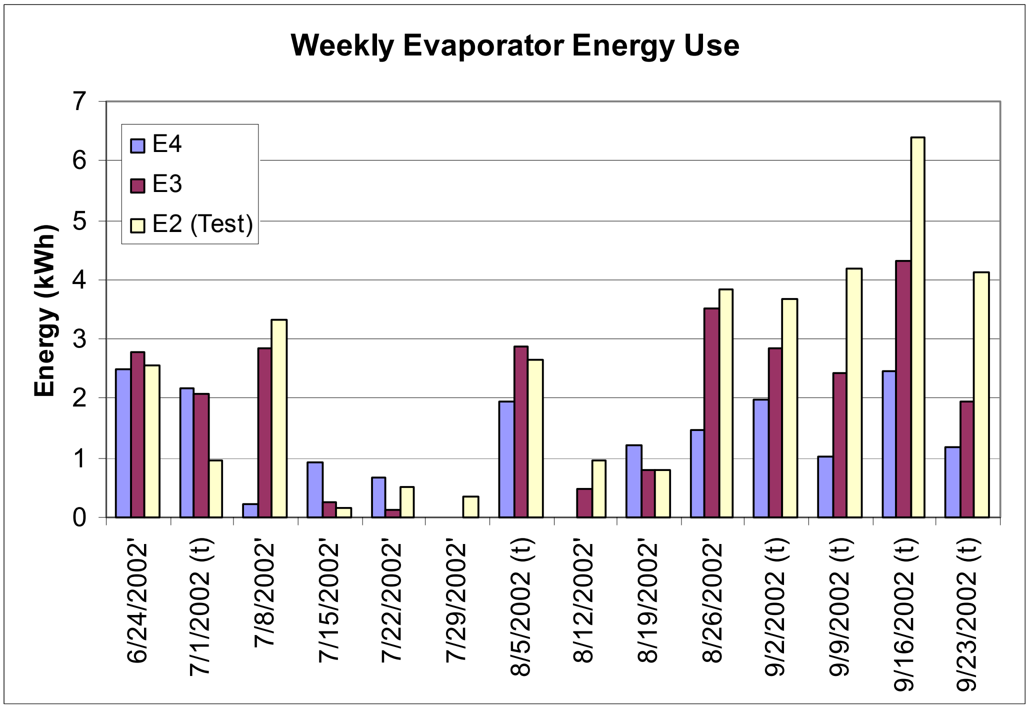

Figure 56 *Evaporator/Heater Weekly Electrical Energy Consumption*

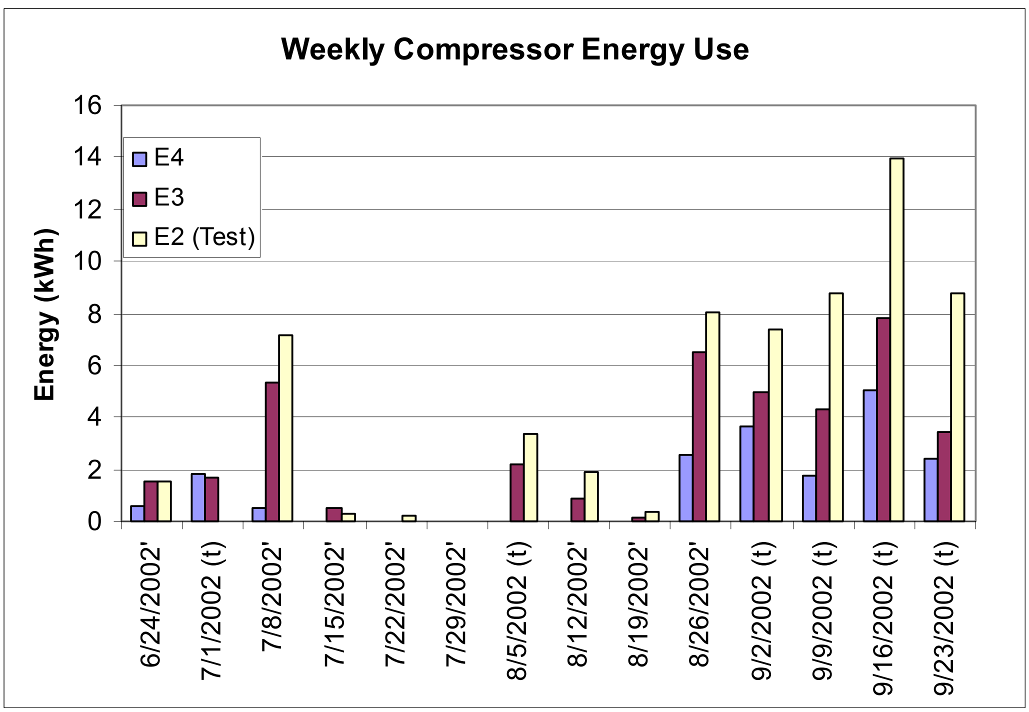

Figure 57 *Compressor Weekly Electrical Energy Consumption*

The energy consumption figures presented in the previous graphs and table show that, with the exception of the week of July 1, nighttime cooling did not cause a diminution in the energy consumed by the compressor of the classroom E2. Classroom E2 used more energy for cooling than classroom E3 and E4. This failure of the nighttime cooling experiment could be attributed to the fact that the exhaust fan was operated longer than necessary causing two possible scenarios:

- The room was cooled excessively prompting the heater to operate and canceling the effect of the pre-cooling;
- Warm air was introduced into the classroom, effectively increasing the cooling load.

Also, the size of the exhaust fan is such that most certainly any savings that could be obtained from the pre-cooling would be offset by the energy necessary to operate the fan. In order to correctly assess the feasibility of nighttime cooling it will be necessary to repeat the experiments with greater control on the fans operation in order to avoid the two scenarios described previously. A proposed plan is presented in the following section.

Experimental Plan

In order to correctly study the feasibility of the nighttime ventilation as a way to reduce the cooling load of the classroom, proper control of the HVAC equipment is needed. The following points need to be addressed or modified

- Temperature controlled ventilation. The fan should operate only when the outside air temperature is below a given threshold and the room temperature is above a certain level. This would prevent the overcooling of the classroom, as well as eliminate the possibility of increasing the cooling load.
- Heater lockout. The heater should be prevented from operating, either by lowering its set point or by disabling it, while the nighttime ventilation is performed.
- Outside air intake dampers need to be opened while the nighttime cooling is being performed. We were informed that in some instances during the past experiment the dampers were closed causing a negative pressure inside the test classroom.
- Exhaust fan energy consumption. The energy used by the exhaust fan during nighttime ventilation needs to be measured (or estimated from the hours of use). We are interested in the net cooling energy savings for the HVAC system due to the nighttime ventilation.
- Use the evaporator fan instead of the exhaust fan. The evaporator fan needs to be operated independently of the compressor unit. The evaporator fan consumes less power than the exhaust fan, and it could be capable to provide the ventilation needed. Furthermore, its energy consumption is currently being monitored.

The points presented above can only be implemented by modifying the program in the energy management system used to control the HVAC equipment in the test classroom.

Meetings with Project Collaborators

PG&E Customer Energy Management Group (June 20, 2002)

Meeting Summary

The purpose of the meeting was to review the results of the benchmarking analysis of the WCCUSD schools energy consumption, and to present the current results of the monitoring of Hanna Ranch and Pinole using the NILM and K20.

Meeting Attendees: Andrea Porter, Project Manager; Pamela Murray; Genrick Gofman, Program Manager; Charlie Nadig, Senior Program Manager; Pamela Peak, Strategic Energy Innovations. Contact information for meeting attendees is presented in Appendix H.

Benchmarking Discussion

- PG&E studied WCCUSD school energy consumption (the source of MIT's school energy data), but used fewer indicators than MIT. Members of the Customer Energy Management group liked the presentation of the data in graphical format, and would like to incorporate the benchmarking graphical results into the energy studies they perform for clients. Currently, the energy studies assess the energy consumption of the clients, but do not provide any information as to where that consumption stands relative to other similar use building in the region.
- Suggestions made to improve the benchmarking analysis were the incorporation of weather data, demand data for the schools and monthly energy consumption. MIT should obtain the monthly data from WCCUSD, although Porter would investigate if PG&E could provide the monthly data to MIT, because WCCUSD already signed a release consent form to PG&E for the original energy study.

School Monitoring Discussion

- The NILM generated positive responses. The ability of the NILM to disaggregate loads using single point metering instead of sub-metering was appealing because PG&E provides clients with Energy Consumption Analysis that involves the installation of power loggers. However, the power loggers are installed by the client and not by PG&E, which has caused problems at the time of collecting the data.
- Andrea Porter asked how much would it cost to install NILMs at other school sites, and how long would it take. She asked this because PG&E is working with the Oakland school district and would like to have more information about the energy consumption than their meters can provide at some of the schools, before they make their recommendation for school improvements.
- Analysis of the energy consumption of the demonstration classrooms at Pinole was welcomed. Pam Murray is working with school designers and officials to promote the use of energy saving measures in schools particularly use of daylight and equipment retrofits.

She suggested more detailed and long term (year long) monitoring of the Pinole classrooms. They would like to use the results as a Case Study to present to clients.

WCCUSD HVAC Maintenance Team (June 24, 2002)

Ed van der Linden arranged a meeting with staff of his HVAC maintenance team. Richard Jackson and Patrick Davis explained in broad terms the operation of the HVAC equipment in Hanna Ranch. They reviewed the program (Insight 2.8) they use to program and monitor the Energy Management System (EMS) at Hanna Ranch. The following EMS parameters were obtained from the system demonstrations:

- The school is divided in two zones with the occupied time for the first zone set from 7:30am to 3:30pm, and for the second zone from 7:33am to 3:30pm.
- HVAC temperature set points are at 68°F for heating, 72°F for economizer (damper), and 74°F for cooling.

When asked about the amount of air conditioning used through out the schools in the district, they stated that the information was not documented. They indicated that as a general rule, schools that have portable classroom units have heat pumps for each classroom, and no A/C in the main buildings of older construction. An empirical list was compiled with approximate A/C coverage in the school based on the personal recollection of Jackson and Davis.

WCCUSD Facilities Design Team (June 25, 2002)

Meeting Summary

The purpose of the meeting was to present the benchmarking analysis of WCCUSD schools energy consumption as well as the results from the monitoring of Pinole Middle School and Hanna Ranch Elementary.

Meeting Attendees: Kevin McQuarie, WLC Architects; Venkatesan Cadambi, WLC Architects; Greg Frucci, WLC Architects; Tom Ventura, Seville Group, Inc.; Dave Bautista, Seville Group, Inc.; Tony Catrino, WCCUSD Facilities; Pamela Peak, Strategic Energy Innovations.

Benchmarking Discussion

- The schools with the best energy performance were retrofitted 5-8 years ago under Gary Freschi's energy savings plan. These retrofits include new furnaces, lower ceilings, new lights
- Primary causes of poor energy performance across several schools are lighting and old equipment and buildings. For example Downer Elementary School is lit with 300W incandescent bulbs, and has old boilers (circa 1910) outside of the building.
- Another cause considered as a possible cause for poor performance is the lack of windows, therefore eliminating the possibility of using daylight or natural ventilation.

- Differences in energy consumption might be attributed to different microclimates. According to school officials, there are three microclimates that can be identified in the WCCUSD geographic area (Two climate zones are identified in Contra Costa County by the California Energy Commission). The effect of the weather should be included in the benchmarking analysis.
- Energy use differences were observed among schools of similar size, orientation and location. For example Ohlone and Hercules have similar construction, orientation and climate, but Hercules consumption is significantly higher than Ohlone. Multiple hypotheses were presented to explain the difference in consumption and are going to be investigated further by Tony Catrino et al. Among them might be the possibility that the Day Care Center at Hercules is hooked to the school electricity meter.
- MIT and WCCUSD should work during this year to include weather data and monthly consumption data into the benchmarking analysis. If needed, WCCUSD could provide network drops and space for additional equipment, such as weather stations.
- Include Hercules Middle/High School into energy analysis.
- In order to save energy at the schools the following steps were recommended to be taken:
    - Behavioral changes. Education of building users.
    - Scheduling changes and equipment maintenance. Reduce cost and energy use by keeping equipment in correct working order, and simple modifications to schedules.
    - Equipment retrofits. These could vary from the installation of simple control devices like timers and motion sensors, to the replacement of older equipment with newer high efficiency equipment. Changes in building insulation and air infiltration.
    - Design changes in buildings, such as daylighting, passive cooling and heating (shading, ventilation, orientation, thermal mass, etc)

School Monitoring Discussion

- Energy consumption results for demonstration classrooms and control classrooms at Pinole Middle School were presented. The lighting retrofits in the demonstration classrooms presented a savings of 20% in energy consumption compared to the lights in the control classrooms
- Hanna Ranch sample of NILM monitoring was presented. An example was shown showcasing the ability of the NILM data to detect abnormal equipment operation. The example used was the rapid on-off cycling of piece of equipment believed to be the A/C. (It was later confirmed that it was the kiln, but the A/C energy use was separated from the kiln via the NILM.)
- Continued monitoring of the demonstration classrooms at Pinole was suggested to obtain conclusive results regarding the energy savings of the multiple retrofits. Next year a new HVAC system in the rooms will be used that was not operational during this year.

- Experiments to be performed at Hanna Ranch were discussed, such as nighttime cooling and the study of A/C energy consumption as a function of various parameters (dead band, set points).
- Nighttime cooling idea raised concerns about comfort, and what the energy implications would be of the room being too cool in the morning, prompting users (or EMS) to use heating before the AC. Guidelines should be developed to address this and other issues.

School Sites Visits (June 21 and 24, 2002)

Pinole Middle School

An inventory of the electrical equipment in both the demonstration classrooms and the control classrooms was performed. Construction and orientation of the classrooms was also studied. The school staff was interviewed in order to learn the class schedules as well as that of the maintenance and non-academic staff. A schematic plan of the school site was obtained, depicting location and type of the various classrooms.

Hanna Ranch Elementary School

The building monitored by the sub-panel NILM was studied. An inventory of the equipment on the electrical panel was performed. The custodian, Rosa Gomez, was interviewed regarding equipment operation, such as the kiln, kiln fan and exhaust fans other than classroom fans, and settings of the nighttime lights.

WCCUSD Facilities Planner and Operations Specialist (June 3, 2003)

MIT researchers (Norford and Lee) met with Tony Catrino, WCCUSD Facilities Planner and Operations Specialist. They were joined by Pam Peak of Strategic Energy Innovations and Saki Kinney and Tim Xu of LBNL. The discussion centered on users of energy information.

The relatively high energy consumption of Downer Elementary School prompted a discussion of school construction and modernization funded by bonds. Catrino noted that it would be useful to predict the benefits and costs, on the basis of measurements in schools that have been improved, of exceeding the requirements of Title 24. Catrino works with a seven-year payback period; beyond that, equipment reliability and maintenance costs are uncertain.

Rehabilitation work will start in Summer 203 for nine schools, with nine more under design development and a third set of nine under schematic design. Design decisions can still be altered for schools in the second phase. Upgrades will include HVAC controls, insulation and new windows. Individual classroom space-conditioning units are desirable, to localize outages. Bonds pay for reconstruction and replacement but not for maintenance, so the performance of energy-saving features over their lifetime is of concern.

Catrino noted that the former (and now retired) Director of Facilities Planning and Construction for WCCUSD, Gary Freschi, took an active interest in improved operation of district schools. Freschi, trained as an electrician, implemented energy controls with the goal of achieving energy savings equal to his salary. Freschi made use of time clocks and more efficient fluorescent tubes and ballasts. As a result, simple energy-conservation measures have been implemented in district schools.

Who has responsibility to monitor school energy use? Freschi was interested, so he did it. Catrino suggested that the district could consider paying the salary of an energy monitoring person from estimated savings. That person could work with such organizations as CEC, LBNL and MIT. The program would need to have a means to sustain itself over time, with due recognition that measurement of savings is a difficult task. At the moment, the district's design team is doing some amount of cost/benefit analysis for school energy upgrades.

Peak noted that a district energy manager could be responsible for education programs that would involve students in energy management and for using the custodial staff to identify energy waste. Catrino again noted the need for seed money to start a program that would be self-sustaining. Without such a program, it is likely that controls will be tampered with, sensors taped over, and filters will clog, undermining energy retrofits.

Catrino stated that benchmarking should be done before and after upgrades. Currently, there is little networking at the district level about energy use, even though it is beneficial to see what others are doing. This could be done via the web, already used to announce surplus furniture. Benchmarking tools are less appealing if they require manual data input.

Catrino considers that there are three climate zones in the district, with Richmond and El Cerrito near water and affected by coastal breeze and fog, San Pablo over a ridge and about 6 F warmer, and Pinole over another ridge and another 6 F warmer in summer conditions.

The use of the NILM was discussed. Catrino noted that it is important to have time-of-day usage, to control demand charges. Further, isolation of refrigeration loads would make possible a cost/benefit analysis of equipment upgrades. Currently, the end-user, the district food service, does not directly pay energy bills and therefore has little incentive to consider efficiency. With energy data, schools could be given an incentive to achieve savings.

Roof-top cooling units are maintained by the heating group within the facilities department. Performance data on the cooling units, potentially produced by the NILM, could contribute to a preventive maintenance program, currently under development. Catrino noted that if the NILM is to be helpful in detecting equipment faults, it would need to flag problems rather than present data. District personnel have no time to look for problems. Diagnostics would be of most benefit if problems could be attributed to a specific cooling unit, which might require low-cost identification through a power-line-carrier device.

Night cooling was discussed. Freschi had experimented with this at Hanna Ranch. Catrino advocated a low-tech solution, with damper controls at the roof and vents through walls, designed to create maximum draft. Air could be drawn in over shaded and therefore cooler concrete, using thermostat control to limit fan operation to hours when the indoor-outdoor temperature difference is large enough to justify use of the fan. Most comfort complaints from students and from staff related to a perception that there is inadequate air movement.

Conclusions

Benchmarking of the energy consumption of the schools in West Contra Costa Unified School District was performed using multiple indicators of energy and cost efficiency. Absolute and relative indicators were used. Absolute indicators were annual energy and consumption and cost for gas and electricity. The relative indicators were cost and energy consumption per unit of reference (student population and building area) as well as energy intensities and densities per hours of operation of the schools. A ranking index was defined using the benchmarking results obtained using the various indicators in order to present the benchmarking results using a single figure.

The benchmarking results helped identify the schools that would benefit the most from applying energy saving measures. These energy saving measures could range from simple building user education and equipment scheduling changes to equipment retrofits and building modifications.

The electrical power consumption of two schools in the district, Pinole Middle School and Hanna Ranch Elementary School, has monitored using Non Intrusive Load Monitoring (NILM) systems and commercially available power metering systems (K20). The main electrical distribution panel in each school was monitored as well as a secondary electrical distribution panel.

The secondary panel in the middle school serves four classrooms in the same wing of the building. Two of these classrooms (demonstration classrooms) were retrofitted with energy efficient lights and controls, while the other two classrooms were left untouched in order to use them as a control set to study the effect on the energy consumption due to the classroom retrofits. During a four-week period, the lights in both demonstration classrooms used 11.5% less energy than the lights in the control classrooms. Individually, one of the demonstration classrooms consumed 21% less energy than the control classrooms while the other classroom only used 3% less energy. Lights that remained on in the demonstration classrooms during long periods of unoccupancy significantly reduced the savings achieved by the new energy efficient lights.

Electricity data collected by the NILMs located at the service entrance in the two schools showed power oscillations that could be identified and tracked and were probably due to refrigeration equipment. Following such loads would provide a means of benchmarking at the equipment rather than whole-building level.

An attempt to assess night cooling in Hanna Ranch did not successfully obtain a complete data set but did demonstrate that running fans at night with no regard for indoor and outdoor temperatures often led to increased cooling loads.

Based on meetings with school officials and others associated with a major school renovation program, there appears to be genuine interest in benchmarking data at the whole-building and component level, provided such data are easily obtained by those who want to use them. The cooperation of all involved, together with their interest in the data, support further interaction with this school district.

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Appendix A Schools Characteristics Data

School	Type	Town	Area (sf)	Students	Hrs/Wk	Mth/Yr	Kitch	% A/C
Bayview	ES	San Pablo	49,781	674	*40*	10	Yes	*0*
Castro	ES	El Cerrito	43,125	412	*40*	10	Yes	*10*
Cesar Chavez	ES	Richmond	43,063	649	*40*	10	Yes	*0*
Collins	ES	Pinole	52,051	513	*40*	10	Yes	*20*
Coronado	ES	Richmond	37,467	426	*40*	10	Yes	*5*
Dover	ES	San Pablo	41,050	731	*40*	10	Yes	*20*
Downer	ES	San Pablo	121,086	957	*40*	12	Yes	*5*
El Sobrante	ES	El Sobrante	33,648	351	*40*	10	Yes	*10*
Ellerhorst	ES	Pinole	37,905	463	*40*	10	Yes	*20*
Fairmont	ES	El Cerrito	34,536	429	*40*	10	Yes	*10*
Ford	ES	Richmond	36,272	521	*40*	10	Yes	*0*
Grant	ES	Richmond	50,211	832	*40*	10	Yes	*0*
Hanna Ranch	ES	Hercules	44,195	496	50	10	Yes	100
Harding	ES	El Cerrito	47,690	438	*50*	10	Yes	*10*
Hercules	ES	Hercules	22,858	340	*40*	10	Yes	100
Highland	ES	Richmond	45,007	677	*40*	10	Yes	*20*
Kensington	ES	Kensington	43,473	520	*40*	10	Yes	*10*
King	ES	Richmond	52,956	551	*40*	10	Yes	*0*
Lake	ES	San Pablo	40,908	457	*40*	10	Yes	*0*
Lincoln	ES	Richmond	43,541	565	*40*	10	Yes	*10*
Madera	ES	El Cerrito	33,929	386	*40*	10	Yes	*10*
Mira Vista	ES	Richmond	49,631	390	*40*	10	Yes	*5*
Montalvin	ES	San Pablo	37,947	356	*40*	10	Yes	*0*
Murphy	ES	Richmond	41,135	440	*40*	10	Yes	*0*
Nystrom	ES	Richmond	70,172	693	*40*	10	Yes	*0*
Ohlone	ES	Hercules	45,561	658	60	10	Yes	100
Olinda	ES	El Sobrante	25,129	359	*40*	10	Yes	*50*
Peres	ES	Richmond	62,322	641	*40*	10	Yes	*0*
Riverside	ES	San Pablo	43,901	337	*40*	10	Yes	*20*
Seaview	ES	San Pablo	25,871	331	*40*	10	Yes	*90*
Shannon	ES	Pinole	25,598	289	*40*	10	Yes	*20*
Sheldon	ES	Richmond	41,742	550	*40*	10	Yes	*0*
Stege	ES	Richmond	42,382	471	50	10	Yes	*0*
Stewart	ES	Pinole	39,487	377	*40*	10	Yes	100
Tara Hills	ES	San Pablo	39,943	469	*40*	10	Yes	*80*
Valley View	ES	Richmond	35,998	410	*40*	10	Yes	*20*
Verde	ES	Richmond	38,837	349	*40*	10	Yes	*90*
Washington	ES	Richmond	36,670	418	*40*	10	Yes	*0*
Wilson	ES	Richmond	46,846	551	*40*	10	Yes	*0*
Adams	MS	Richmond	123,803	1097	40	12	Yes	0
Crespi	MS	El Sobrante	125,000	1088	60	10	Yes	10
Helms	MS	San Pablo	158,682	1283	40	10	Yes	10
Pinole	MS	Pinole	78,313	953	75	10	Yes	50
Portola	MS	El Cerrito	126,852	1040	40	10	Yes	20
DeAnza	HS	Richmond	177,762	1438	40	12	Yes	40
El Cerrito	HS	El Cerrito	173,259	1410	40	12	Yes	50
Kennedy	HS	Richmond	189,841	1026	40	10	Yes	100
Pinole Valley	HS	Pinole	160,915	2167	50	10	Yes	40
Richmond	HS	Richmond	226,510	1644	75	10	Yes	100

Appendix B School Energy Consumption Data

School	Elect (kWh)	Gas (Therm)	Total (kBtu)	Contribution Elect	Contribution Gas	Elect Cost	Gas Cost	Total Cost	Contribution Elect	Contribution Gas
Bayview	189559	8216	1468379	44%	56%	$21,197	$5,219	$26,416	80%	20%
Castro	106468	8823	1245565	29%	71%	$11,887	$6,109	$17,996	66%	34%
Cesar Chavez	161242	2335	783667	70%	30%	$16,374	$1,800	$18,174	90%	10%
Collins	146160	16494	2148086	23%	77%	$16,220	$10,613	$26,833	60%	40%
Coronado	111812	8347	1216200	31%	69%	$12,656	$5,295	$17,951	71%	29%
Dover	151807	7800	1297967	40%	60%	$16,896	$5,191	$22,087	76%	24%
Downer	488185	57536	7419245	22%	78%	$51,681	$34,560	$86,241	60%	40%
El Sobrante	83781	5370	822860	35%	65%	$8,930	$3,509	$12,439	72%	28%
Ellerhorst	109939	6592	1034311	36%	64%	$12,818	$4,380	$17,198	75%	25%
Fairmont	80220	4845	758210	36%	64%	$8,137	$3,189	$11,326	72%	28%
Ford	103923	3306	685189	52%	48%	$11,027	$2,398	$13,425	82%	18%
Grant	169211	7840	1361350	42%	58%	$18,465	$5,484	$23,949	77%	23%
Hanna Ranch	185120	2410	872641	72%	28%	$22,064	$1,680	$23,744	93%	7%
Harding	159362	7281	1271846	43%	57%	$17,140	$4,837	$21,977	78%	22%
Hercules	174720	2911	887255	67%	33%	$18,316	$1,716	$20,032	91%	9%
Highland	127462	2693	704207	62%	38%	$13,622	$1,814	$15,436	88%	12%
Kensington	134502	7243	1183221	39%	61%	$13,466	$4,812	$18,278	74%	26%
King	203910	5214	1217150	57%	43%	$23,117	$3,622	$26,739	86%	14%
Lake	186313	3245	960210	66%	34%	$20,483	$2,220	$22,703	90%	10%
Lincoln	120560	7540	1165350	35%	65%	$14,078	$5,353	$19,431	72%	28%
Madera	145655	7937	1290675	39%	61%	$16,354	$4,789	$21,143	77%	23%
Mira Vista	162634	8268	1381709	40%	60%	$18,366	$5,505	$23,871	77%	23%
Montalvin	90480	3326	641320	48%	52%	$8,280	$2,088	$10,368	80%	20%
Murphy	107027	17161	2081260	18%	82%	$11,893	$11,624	$23,517	51%	49%
Nystrom	168381	13171	1891611	30%	70%	$17,898	$8,820	$26,718	67%	33%
Ohlone	241618	300	854420	96%	4%	$26,481	$312	$26,793	99%	1%
Olinda	103082	4376	789318	45%	55%	$11,172	$2,888	$14,060	79%	21%
Peres	162080	14749	2027909	27%	73%	$18,155	$9,828	$27,983	65%	35%
Riverside	113557	7402	1127655	34%	66%	$12,771	$5,024	$17,795	72%	28%
Seaview	138026	2737	744652	63%	37%	$15,311	$1,968	$17,279	89%	11%
Shannon	113050	3031	688831	56%	44%	$11,812	$2,034	$13,846	85%	15%
Sheldon	127777	8634	1299373	34%	66%	$13,261	$5,637	$18,898	70%	30%
Stege	144635	1743	667804	74%	26%	$15,170	$1,480	$16,650	91%	9%
Stewart	133031	5558	1009705	45%	55%	$14,081	$3,736	$17,817	79%	21%
Tara Hills	183120	9446	1569407	40%	60%	$19,363	$5,643	$25,006	77%	23%
Valley View	122175	6094	1026262	41%	59%	$14,087	$3,911	$17,998	78%	22%
Verde	182560	13330	1955890	32%	68%	$19,199	$8,940	$28,139	68%	32%
Washington	113910	13573	1745951	22%	78%	$11,564	$8,616	$20,180	57%	43%
Wilson	110250	10003	1376468	27%	73%	$11,917	$6,678	$18,595	64%	36%
Adams	390377	35958	4927747	27%	73%	$40,016	$24,861	$64,877	62%	38%
Crespi	381600	29700	4272008	30%	70%	$38,332	$19,604	$57,936	66%	34%
Helms	375653	24285	3710224	35%	65%	$37,712	$9,862	$47,574	79%	21%
Pinole	356920	7699	1987729	61%	39%	$37,734	$5,015	$42,749	88%	12%
Portola	343048	29437	4114166	28%	72%	$34,633	$19,275	$53,908	64%	36%

School	Elect (kWh)	Gas (Therm)	Total (kBtu)	Contribution		Elect Cost	Gas Cost	Total Cost	Contribution	
				Elect	Gas				Elect	Gas
DeAnza	889516	30976	6132656	49%	51%	$85,956	$19,621	$105,577	81%	19%
El Cerrito	811517	58347	8603578	32%	68%	$78,485	$38,929	$117,414	67%	33%
Kennedy	1274853	32410	7590855	57%	43%	$124,254	$20,735	$144,989	86%	14%
Pinole Valley	1039381	34908	7037202	50%	50%	$103,819	$21,310	$125,129	83%	17%
Richmond	1548689	21429	7427120	71%	29%	$175,014	$13,892	$188,906	93%	7%

Appendix C School Energy Consumption per Student

School	Energy Density (kBtu/Student)			Cost per Student		
	Electricity	Gas	Total	Electricity	Gas	Total
Bayview	959.16	1218.37	2177.53	$31.43	$7.74	$39.17
Castro	881.03	2139.74	3020.77	$28.83	$14.82	$43.64
Cesar Chavez	848.16	359.96	1208.12	$25.24	$2.77	$28.02
Collins	972.14	3215.16	4187.30	$31.62	$20.69	$52.31
Coronado	896.27	1960.90	2857.16	$29.73	$12.44	$42.17
Dover	708.59	1067.02	1775.60	$23.11	$7.10	$30.21
Downer	1740.57	6012.04	7752.61	$54.00	$36.11	$90.12
El Sobrante	813.66	1528.44	2342.11	$25.42	$9.99	$35.41
Ellerhorst	809.61	1422.71	2232.33	$27.66	$9.45	$37.12
Fairmont	638.53	1130.23	1768.76	$18.98	$7.44	$26.42
Ford	680.17	634.13	1314.30	$21.15	$4.60	$25.75
Grant	693.67	941.92	1635.58	$22.18	$6.59	$28.77
Hanna Ranch	1274.33	486.21	1760.54	$44.51	$3.39	$47.90
Harding	1242.40	1663.57	2905.97	$39.16	$11.05	$50.21
Hercules	1753.41	856.16	2609.57	$53.87	$5.05	$58.92
Highland	642.41	397.78	1040.19	$20.12	$2.68	$22.80
Kensington	882.00	1391.97	2273.97	$25.88	$9.25	$35.13
King	1261.95	945.69	2207.65	$41.93	$6.57	$48.50
Lake	1392.08	710.57	2102.65	$44.85	$4.86	$49.71
Lincoln	728.07	1334.49	2062.57	$24.92	$9.47	$34.39
Madera	1287.53	2056.19	3343.72	$42.37	$12.41	$54.77
Mira Vista	1421.66	2118.16	3539.82	$47.05	$14.10	$61.16
Montalvin	868.02	935.13	1803.15	$23.28	$5.87	$29.15
Murphy	830.59	3903.13	4733.72	$27.05	$26.44	$53.49
Nystrom	829.05	1900.55	2729.60	$25.83	$12.73	$38.55
Ohlone	1252.28	45.57	1297.85	$40.22	$0.47	$40.70
Olinda	979.73	1218.92	2198.66	$31.12	$8.04	$39.16
Peres	863.21	2302.10	3165.31	$28.34	$15.34	$43.68
Riverside	1148.61	2194.24	3342.85	$37.86	$14.89	$52.75
Seaview	1422.83	826.88	2249.70	$46.26	$5.95	$52.20
Shannon	1334.73	1048.77	2383.50	$40.87	$7.04	$47.91
Sheldon	792.70	1569.80	2362.50	$24.11	$10.25	$34.36
Stege	1048.53	370.32	1418.85	$32.23	$3.14	$35.38
Stewart	1204.01	1474.25	2678.26	$37.35	$9.91	$47.26
Tara Hills	1332.24	2014.04	3346.28	$41.29	$12.03	$53.32
Valley View	1016.76	1486.32	2503.08	$34.36	$9.54	$43.90

School	Energy Density (kBtu/Student)			Cost per Student		
	Electricity	Gas	Total	Electricity	Gas	Total
Verde	1783.14	3815.79	5598.92	$54.96	$25.59	$80.55
Washington	930.57	3249.67	4180.25	$27.69	$20.63	$48.32
Wilson	682.31	1814.30	2496.62	$21.61	$12.11	$33.73
Adams MS	1214.22	3277.80	4492.02	$36.48	$22.66	$59.14
Crespi MS	1196.74	2729.74	3926.48	$35.23	$18.02	$53.25
Helms MS	999.03	1892.80	2891.83	$29.39	$7.69	$37.08
Pinole MS	1277.90	807.86	2085.76	$39.59	$5.26	$44.86
Portola MS	1125.49	2830.44	3955.93	$33.30	$18.53	$51.83
DeAnza HS	2110.64	2154.07	4264.71	$59.77	$13.64	$73.42
El Cerrito HS	1963.80	4138.03	6101.83	$55.66	$27.61	$83.27
Kennedy HS	4239.67	3158.82	7398.49	$121.11	$20.21	$141.31
Pinole Valley HS	1636.57	1610.87	3247.44	$47.91	$9.83	$57.74
Richmond HS	3214.26	1303.45	4517.71	$106.46	$8.45	$114.91

Appendix D School Energy Consumption per Unit Area

School	Energy Intensity (kBtu/ft^2)			Cost per ft^2		
	Electricity	Gas	Total	Electricity	Gas	Total
Bayview	12.99	16.50	29.50	$0.43	$0.10	$0.53
Castro	8.42	20.46	28.88	$0.28	$0.14	$0.42
Cesar Chavez	12.78	5.42	18.20	$0.38	$0.04	$0.42
Collins	9.58	31.69	41.27	$0.31	$0.20	$0.52
Coronado	10.18	22.28	32.46	$0.34	$0.14	$0.48
Dover	12.62	19.00	31.62	$0.41	$0.13	$0.54
Downer	13.76	47.52	61.27	$0.43	$0.29	$0.71
El Sobrante	8.50	15.96	24.45	$0.27	$0.10	$0.37
Ellerhorst	9.90	17.39	27.29	$0.34	$0.12	$0.45
Fairmont	7.93	14.03	21.95	$0.24	$0.09	$0.33
Ford	9.78	9.11	18.89	$0.30	$0.07	$0.37
Grant	11.50	15.61	27.11	$0.37	$0.11	$0.48
Hanna Ranch	14.29	5.45	19.75	$0.50	$0.04	$0.54
Harding	11.40	15.27	26.67	$0.36	$0.10	$0.46
Hercules	26.08	12.73	38.82	$0.80	$0.08	$0.88
Highland	9.66	5.98	15.65	$0.30	$0.04	$0.34
Kensington	10.56	16.66	27.22	$0.31	$0.11	$0.42
King	13.14	9.85	22.98	$0.44	$0.07	$0.50
Lake	15.54	7.93	23.47	$0.50	$0.05	$0.55
Lincoln	9.45	17.32	26.76	$0.32	$0.12	$0.45
Madera	14.65	23.39	38.04	$0.48	$0.14	$0.62
Mira Vista	11.18	16.66	27.84	$0.37	$0.11	$0.48
Montalvin	8.14	8.76	16.90	$0.22	$0.06	$0.27
Murphy	8.88	41.72	50.60	$0.29	$0.28	$0.57
Nystrom	8.19	18.77	26.96	$0.26	$0.13	$0.38

School	Energy Intensity (kBtu/ft^2)			Cost per ft^2		
	Electricity	Gas	Total	Electricity	Gas	Total
Ohlone	18.09	0.66	18.75	$0.58	$0.01	$0.59
Olinda	14.00	17.41	31.41	$0.44	$0.11	$0.56
Peres	8.87	23.67	32.54	$0.29	$0.16	$0.45
Riverside	8.83	16.86	25.69	$0.29	$0.11	$0.41
Seaview	18.20	10.58	28.78	$0.59	$0.08	$0.67
Shannon	15.07	11.84	26.91	$0.46	$0.08	$0.54
Sheldon	10.44	20.68	31.13	$0.32	$0.14	$0.45
Stege	11.64	4.11	15.76	$0.36	$0.03	$0.39
Stewart	11.50	14.08	25.57	$0.36	$0.09	$0.45
Tara Hills	15.64	23.65	39.29	$0.48	$0.14	$0.63
Valley View	11.58	16.93	28.51	$0.39	$0.11	$0.50
Verde	16.04	34.32	50.36	$0.49	$0.23	$0.72
Washington	10.60	37.01	47.61	$0.32	$0.23	$0.55
Wilson	8.03	21.35	29.38	$0.25	$0.14	$0.40
Adams MS	10.76	29.04	39.80	$0.32	$0.20	$0.52
Crespi MS	10.42	23.76	34.18	$0.31	$0.16	$0.46
Helms MS	8.08	15.30	23.38	$0.24	$0.06	$0.30
Pinole MS	15.55	9.83	25.38	$0.48	$0.06	$0.55
Portola MS	9.23	23.21	32.43	$0.27	$0.15	$0.42
DeAnza HS	17.07	17.43	34.50	$0.48	$0.11	$0.59
El Cerrito HS	15.98	33.68	49.66	$0.45	$0.22	$0.68
Kennedy HS	22.91	17.07	39.99	$0.65	$0.11	$0.76
Pinole Valley HS	22.04	21.69	43.73	$0.65	$0.13	$0.78
Richmond HS	23.33	9.46	32.79	$0.77	$0.06	$0.83

Appendix E Time Normalized Relative Energy Consumption

School	Energy Intensity per Hour (kBtu/ft^2-hr)			Energy per Student-Hour (kBtu/person-hr)		
	Electricity	Gas	Total	Electricity	Gas	Total
Bayview	1.624	2.063	3.69	119.9	152.3	272.19
Castro	1.053	2.557	3.61	110.1	267.5	377.60
Cesar Chavez	1.597	0.678	2.27	106.0	45.0	151.02
Collins	1.198	3.961	5.16	121.5	401.9	523.41
Coronado	1.273	2.785	4.06	112.0	245.1	357.15
Dover	1.577	2.375	3.95	88.6	133.4	221.95
Downer	1.720	5.939	7.66	217.6	751.5	969.08
El Sobrante	1.062	1.995	3.06	101.7	191.1	292.76
Ellerhorst	1.237	2.174	3.41	101.2	177.8	279.04
Fairmont	0.991	1.754	2.74	79.8	141.3	221.10
Ford	1.222	1.139	2.36	85.0	79.3	164.29
Grant	1.437	1.952	3.39	86.7	117.7	204.45
Hanna Ranch	1.429	0.545	1.97	127.4	48.6	176.05

School	Energy Intensity per Hour ($kBtu/ft^2$-hr)			Energy per Student-Hour (kBtu/person-hr)		
	Electricity	Gas	Total	Electricity	Gas	Total
Harding	1.425	1.908	3.33	155.3	207.9	363.25
Hercules	3.260	1.592	4.85	219.2	107.0	326.20
Highland	1.208	0.748	1.96	80.3	49.7	130.02
Kensington	1.320	2.083	3.40	110.2	174.0	284.25
King	1.642	1.231	2.87	157.7	118.2	275.96
Lake	1.943	0.992	2.93	174.0	88.8	262.83
Lincoln	1.181	2.165	3.35	91.0	166.8	257.82
Madera	1.831	2.924	4.76	160.9	257.0	417.96
Mira Vista	1.398	2.082	3.48	177.7	264.8	442.48
Montalvin	1.017	1.096	2.11	108.5	116.9	225.39
Murphy	1.110	5.215	6.32	103.8	487.9	591.72
Nystrom	1.023	2.346	3.37	103.6	237.6	341.20
Ohlone	1.508	0.055	1.56	104.4	3.8	108.15
Olinda	1.750	2.177	3.93	122.5	152.4	274.83
Peres	1.109	2.958	4.07	107.9	287.8	395.66
Riverside	1.103	2.108	3.21	143.6	274.3	417.86
Seaview	2.276	1.322	3.60	177.9	103.4	281.21
Shannon	1.884	1.480	3.36	166.8	131.1	297.94
Sheldon	1.306	2.585	3.89	99.1	196.2	295.31
Stege	1.164	0.411	1.58	104.9	37.0	141.88
Stewart	1.437	1.759	3.20	150.5	184.3	334.78
Tara Hills	1.955	2.956	4.91	166.5	251.8	418.29
Valley View	1.448	2.116	3.56	127.1	185.8	312.88
Verde	2.005	4.290	6.30	222.9	477.0	699.87
Washington	1.325	4.627	5.95	116.3	406.2	522.53
Wilson	1.004	2.669	3.67	85.3	226.8	312.08
Adams MS	1.655	4.468	4.31	186.8	504.3	533.09
Crespi MS	0.868	1.980	6.21	99.7	227.5	762.73
Helms MS	1.010	1.913	4.00	124.9	236.6	739.85
Pinole MS	1.003	0.634	4.16	82.4	52.1	309.28
Portola MS	1.153	2.901	2.12	140.7	353.8	291.47
DeAnza HS	2.134	2.178	6.12	263.8	269.3	691.08
El Cerrito HS	1.998	4.209	2.85	245.5	517.3	327.21
Kennedy HS	2.291	1.707	2.92	424.0	315.9	361.48
Pinole Valley HS	2.099	2.066	1.64	155.9	153.4	134.57
Richmond HS	1.505	0.610	4.05	207.4	84.1	494.49

Appendix F School Rankings Based on Analysis

Rank	Energy per Area	Cost per Area	Energy per Student	Cost per Student	Energy per Student-Hr	Energy per ft^2-Hr	Total Energy	Total Cost
1	Highland	Montalvin	Highland	Highland	Ohlone	Ohlone	Montalvin	Montalvin
2	Stege	Helms MS	Cesar Chavez	Ford	Highland	Stege	Stege	Fairmont

Rank	Energy per Area	Cost per Area	Energy per Student	Cost per Student	Energy per Student-Hr	Energy per ft^2-Hr	Total Energy	Total Cost
3	Montalvin	Fairmont	Ohlone	Fairmont	Pinole MS	Pinole MS	Ford	El Sobrante
4	Cesar Chavez	Highland	Ford	Cesar Chavez	Stege	Highland	Shannon	Ford
5	Ohlone	El Sobrante	Stege	Grant	Cesar Chavez	Hanna Ranch	Highland	Shannon
6	Ford	Ford	Grant	Montalvin	Ford	Montalvin	Seaview	Olinda
7	Hanna Ranch	Nystrom	Hanna Ranch	Dover	Hanna Ranch	Richmond HS	Fairmont	Highland
8	Fairmont	Stege	Fairmont	Wilson	Grant	Cesar Chavez	Cesar Chavez	Stege
9	King	Wilson	Dover	Sheldon	Fairmont	Ford	Olinda	Ellerhorst
10	Helms MS	Riverside	Montalvin	Lincoln	Dover	Fairmont	El Sobrante	Seaview
11	Lake	Castro	Lincoln	Kensington	Montalvin	Crespi MS	Ohlone	Riverside
12	El Sobrante	Kensington	Pinole MS	Stege	Lincoln	King	Hanna Ranch	Stewart
13	Pinole MS	Cesar Chavez	Lake	El Sobrante	Lake	Helms MS	Hercules	Coronado
14	Stewart	Portola MS	Bayview	Helms MS	Bayview	Lake	Lake	Castro
15	Riverside	Lincoln	Olinda	Ellerhorst	Olinda	El Sobrante	Stewart	Valley View
16	Harding	Peres	King	Nystrom	King	Stewart	Valley View	Cesar Chavez
17	Lincoln	Stewart	Ellerhorst	Olinda	Ellerhorst	Riverside	Ellerhorst	Kensington
18	Shannon	Sheldon	Seaview	Bayview	Seaview	Harding	Riverside	Wilson
19	Nystrom	Ellerhorst	Kensington	Ohlone	Kensington	Lincoln	Lincoln	Sheldon
20	Grant	Harding	El Sobrante	Coronado	Richmond HS	Shannon	Kensington	Lincoln
21	Kensington	Crespi MS	Sheldon	Castro	El Sobrante	Nystrom	Coronado	Hercules
22	Ellerhorst	Grant	Shannon	Peres	Sheldon	Grant	King	Washington
23	Mira Vista	Coronado	Wilson	Valley View	Shannon	Kensington	Castro	Madera
24	Valley View	Mira Vista	Valley View	Pinole MS	Pinole Valley	Ellerhorst	Harding	Harding
25	Seaview	Valley View	Hercules	Stewart	Wilson	Mira Vista	Madera	Dover
26	Castro	King	Stewart	Hanna Ranch	Valley View	Valley View	Dover	Lake
27	Wilson	Collins	Nystrom	Shannon	Hercules	Seaview	Sheldon	Murphy
28	Bayview	Adams MS	Coronado	Washington	Crespi MS	Castro	Grant	Hanna Ranch
29	Sheldon	Bayview	Helms MS	King	Stewart	Wilson	Wilson	Mira Vista
30	Olinda	Hanna Ranch	Harding	Lake	Nystrom	Bayview	Mira Vista	Grant
31	Dover	Dover	Castro	Harding	Coronado	Sheldon	Bayview	Tara Hills
32	Portola MS	Shannon	Peres	Portola MS	Helms MS	Olinda	Tara Hills	Bayview
33	Coronado	Pinole MS	Pinole Valley	Seaview	Harding	Dover	Washington	Nystrom
34	Peres	Washington	Riverside	Collins	Castro	Kennedy HS	Nystrom	King
35	Richmond HS	Lake	Madera	Riverside	Peres	Portola MS	Verde	Ohlone
36	Crespi MS	Olinda	Tara Hills	Crespi MS	Riverside	Coronado	Pinole MS	Collins
37	DeAnza HS	Murphy	Mira Vista	Tara Hills	Madera	Peres	Peres	Peres
38	Madera	Ohlone	Crespi MS	Murphy	Tara Hills	Pinole Valley	Murphy	Verde
39	Hercules	DeAnza HS	Portola MS	Madera	Mira Vista	DeAnza HS	Collins	Pinole MS
40	Tara Hills	Madera	Washington	Pinole Valley	Portola MS	Madera	Helms MS	Helms MS
41	Adams MS	Tara Hills	Collins	Hercules	Washington	Hercules	Portola MS	Portola MS
42	Kennedy HS	Seaview	DeAnza HS	Adams MS	Collins	Tara Hills	Crespi MS	Crespi MS
43	Collins	El Cerrito HS	Adams MS	Mira Vista	DeAnza HS	Collins	Adams MS	Adams MS
44	Pinole Valley	Downer	Richmond HS	DeAnza HS	Murphy	Washington	DeAnza HS	Downer
45	Washington	Verde	Murphy	Verde	Adams MS	Adams MS	Pinole Valley	DeAnza HS
46	El Cerrito HS	Kennedy HS	Verde	El Cerrito HS	Verde	El Cerrito HS	Downer	El Cerrito HS
47	Verde	Pinole Valley	El Cerrito HS	Downer	Kennedy HS	Verde	Richmond HS	Pinole Valley
48	Murphy	Richmond HS	Kennedy HS	Richmond HS	El Cerrito HS	Murphy	Kennedy HS	Kennedy HS
49	Downer	Hercules	Downer	Kennedy HS	Downer	Downer	El Cerrito HS	Richmond HS

Appendix G WCCUSD Ranking Results

Ranking Index		Star Score	
Highland	3	Ford	99
Ford	4	Highland	99
Montalvin	4	Cesar Chavez	98
Stege	5	Fairmont	98
Fairmont	6	Montalvin	98
Cesar Chavez	7	El Sobrante	97
El Sobrante	11	Grant	97
Hanna Ranch	14	Hanna Ranch	97
Lincoln	14	Stege	97
Ohlone	14	Dover	96
Ellerhorst	16	Lincoln	96
Grant	16	Ellerhorst	95
Kensington	17	Kensington	95
Olinda	19	Olinda	95
Shannon	19	Wilson	95
Dover	20	Castro	94
King	20	Ohlone	94
Lake	20	Sheldon	94
Stewart	20	Valley View	94
Wilson	20	Bayview	93
Sheldon	21	Coronado	93
Pinole MS	21	Nystrom	93
Castro	22	Shannon	93
Riverside	22	King	92
Seaview	22	Lake	92
Valley View	22	Riverside	92
Nystrom	23	Seaview	92
Helms MS	23	Stewart	92
Bayview	24	Harding	90
Coronado	25	Peres	90
Harding	25	Pinole MS	90
Mira Vista	31	Helms MS	88
Peres	31	Mira Vista	87
Hercules	32	Madera	86
Crespi MS	32	Hercules	84
Madera	34	Tara Hills	84
Portola MS	35	Washington	84
Washington	36	Collins	83
Tara Hills	37	Murphy	82
Richmond HS	37	Crespi MS	81
Collins	38	Portola MS	77
Murphy	40	Adams MS	69
Pinole Valley HS	40	Richmond HS	69
Adams MS	41	Verde	66
DeAnza HS	42	Downer	59
Verde	43	DeAnza HS	59
Kennedy HS	45	Pinole Valley HS	59
Downer	46	Kennedy HS	52
El Cerrito HS	46	El Cerrito HS	51

Appendix H Meeting Attendees Contact Information

PG&E Customer Energy Management Group

Group Mailing Address:

Mail Code N6G
Pacific Gas & Electric Company
P.O. Box 770000
San Francisco, CA 94177-0001

Gofman, Genrick
Program Manager
245 Market St, Room 692B
San Francisco, CA 94105-1702
Ph: 415.973.4007
Fax: 415.973.0580
GXGO@pge.com

Murray, Pam
245 Market St, Room 641C
San Francisco, CA 94105-1702
Ph: 415.972.5416
Fax: 415.973.4961
Pager: 415.998.5579
PMW2@pge.com

Nadig, Charlie
Senior Program Manager
245 Market St, Room 619C
San Francisco, CA 94105-1702
Ph: 415.973.4790
Fax: 415.973.1234
Cell: 925.984.5944
CWN2@pge.com

Porter, Andrea
Project Manager
245 Market St. Room 643A
San Francisco, CA 94105-1702
Ph: 415.972.5232
Fax: 415.973.4961
agp1@pge.com

Strategic Energy Innovations

Peak, Pamela
Project Coordinator
175 North Redwood Dr., Suite 150
San Rafael, CA 94903
Ph: 415.507.2182
Fax: 415.507.1975
pam@SEIinc.org

The Seville Group, Inc.

Bautista, Dave
1300 Potrero Ave
Richmond, CA 94804
Ph: 510.412.5657
Fax: 510.412.5661
dbautista@sevillegroup.com

Ventura, Tom
Senior Project Manager
1300 Potrero Ave
Richmond, CA 94804
Ph: 510.412.8806
Ph: 510.412.5657
Fax: 510.412.5661
Cell: 510.377.4023
tventura@sevillegroup.com

West Contra Costa Unified School District

Catrino, Tony
Operation Specialist
1300 Potrero Ave
Richmond, CA 94804-3729
Ph: 510.412.4367
Fax: 510.620.3162
tcatrino@wccusd.k12.ca.us

Cornell, Mike
Telephone Systems Technician
1300 Potrero Ave
Richmond, CA 94804-3729
Ph: 510.412.9130
Ph: 510.620.2020
Fax: 510.231.1992
Cell: 510.812.0520
mcornell@wccusd.k12.ca.us

Davis, Patrick
Maintenance Technician
125 South 8th St
Richmond, CA 94804-2321
Ph: 510.233.0104

Gomez, Rosa
Head Custodian
Hanna Ranch Elementary School
2482 Refugio Valley Rd
Hercules, CA 94547
Ph: 510.245.9902
Fax: 510.799.5795

Jackson, Richard
Maintenance Supervisor
125 South 8th St
Richmond, CA 94804-2321
Ph: 510.233.0104

Van der Linden, Ed
Manager of Maintenance
125 South 8th St
Richmond, CA 94804-2321
Ph: 510.233.0104
Ph: 510.620.2159
Fax: 510.237.6350
Cell: 510.812.0368
evanderlinden@wccusd.k12.ca.us

WLC Architects, Incorporated

Frucci, Greg
Project Architect
1300 Potrero Ave
Richmond, CA 94804-3748
Ph: 510.412.5657
Fax: 510.412.5661
gfrucci@wlc-architects.com

MacQuarrie, Kevin
AIA Associate
1300 Potrero Ave
Richmond, CA 94804-3748
Ph: 510.412.5657
Fax: 510.412.5661
kevin@wlc-architects.com

Venkatesan, Cadambi
Design Team Architect
1300 Potrero Ave
Richmond, CA 94804-3748
Ph: 510.412.5657
Fax: 510.412.5661
ven@wlc-architects.com